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Photographic SCIENCE AND ENGINEERING

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PHOTOGRAPHIC SCIENCE AND ENGINEERING
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Stability of Selenium Xerographic Plates to Nuclear Radiation

M. LEVY AND R. M. BLAKNEY, *Physics of Materials Department, Haloid Xerox Inc., Rochester, N.Y.*

Several types of selenium xerographic plates were given the following exposures to nuclear radiation: 10^3 roentgens/sq cm and 10^5 roentgens/sq cm γ-radiation; 10^{13} neutrons/sq cm thermal neutrons. No significant change in the xerographic properties of these plates was subsequently observed. A comparison of the relative stability of xerographic plates and silver halide emulsions is made, and it is shown that xerographic plates can withstand at least one thousand times more exposure to cobalt-60 γ-radiation than silver halide emulsions can.

Xerography is an electrostatic photographic system based directly on the phenomenon of photoconductivity.[1] The photosensitive element, most commonly an amorphous selenium plate, is first electrostatically charged in the dark by corona discharge, then exposed to a subject. Since amorphous selenium is photoconductive, the charge pattern remaining on the plate corresponds to the unexposed areas. This electrostatic latent image is developed by dusting the surface with a charged powder.

A major area of application for xerography lies in direct photography. Of considerable interest in this application is the effect of intense nuclear radiation on the properties of xerographic plates. The present investigation sought to determine if any permanent changes occur in the photographic capabilities of xerographic plates as a result of such radiations.

Two distinct problems arise in this connection. These are, first, the stability of plates under storage conditions of high background radiation fluxes, and, second, the performance of plates in areas of high-level nuclear radiations. The present investigation was directed solely at the first problem and demonstrated that amorphous selenium xerographic plates sustain no permanent damage as a result of intense nuclear irradition.

Experimental Procedure

Two similar experiments were performed. In the first, several types of amorphous selenium xerographic plates were subjected to cobalt-60 γ-radiation. In the second, selenium plates were irradiated with thermal neutrons in the pile at the Brookhaven National Laboratories. The procedure for the two experiments differed in detail, but their general pattern was the same.

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In each experiment, an attempt was made to test as many types of plates as was experimentally feasible. Samples for irradiation and controls comprised 2-in. squares cut from large plates. This procedure was followed to eliminate any minor differences among samples arising from manufacture. Each large plate was evaluated prior to cutting the smaller samples from it.

Measurements

A unique feature of xerography is the ability to evaluate the photographic capabilities of the photosensitive element by purely electrical measurements without recourse to the development step. The operational characteristics of plates can be determined quickly and completely with a few simple electrometer measurements. The first of these is dark decay which is a quantitative expression of the degree to which plate surface charge is retained in the dark. The better a plate retains its charge in the dark, the greater is the photographically available contrast. Dark decay is obtained by measuring the decrease in plate surface potential in the dark during the 3-min interval immediately following electrostatic charging. (Since a plate in the charged state may be regarded as a capacitor, surface potential and surface charge are directly proportional.) Dark decay, D_3, is expressed quantitatively as the percent change in surface potential referred to the initial surface potential. Plates having dark decays up to 25% are acceptable for all but the most demanding applications.

A second important characteristic of reusable xerographic plates is the persistence of conductivity in the exposed regions after the exposure has been completed. This is evidenced, on subsequent charging, by an increased dark decay, D_3, in the previously exposed areas. It can be termed a "memory" or fatigue effect. If the previous exposure was an image, in contrast to a general plate exposure, a weak rendition of the image may appear in subsequent uses. This persistent conductivity or fatigue disappears

with time. It is desirable, however, that the fatigue, K_3, be low. Fatigue is determined from the difference in dark potential 3 min after charging, between an area of the plate which has been in the dark for about one-half hour and an area which has been exposed to heavy illumination just prior to being charged. Quantitatively it is expressed in percent as the ratio of this difference to the 3-min potential in the unexposed region. Usually K_3 is less than 10%. However, some samples with higher K_3 were included in the present work to determine if it is a significant parameter in relation to radiation damage.

A third characteristic of importance is the residual potential, V_R. It is the potential to which a plate is reduced by being heavily overexposed. A plate which has a very high residual potential is essentially insensitive to radiation, i.e. radiation cannot reduce the plate potential sufficiently to yield significant contrast between exposed and unexposed regions. Residual potential increases, in general, with thickness of the photoconductive layer. Values near zero are usually found for layers 50 μ thick, with increase to the neighborhood of 100 v for 160 μ films.

The three parameters, dark decay (D_3), light fatigue (K_3), and residual potential (V_R), describe the important xerographic characteristics of the plate. The image-forming ability of the plate is directly related to these characteristics and their numerical values must be in the stated ranges for satisfactory operation. A *major* change in one of these parameters, as a result of irradiation, would affect the image-forming ability of the plate and establishes a criterion for determining radiation damage.

Irradiation

Gamma irradiation was performed at a cobalt-60 source located at the University of Rochester. The plates were subjected to exposures of about 10^5 roentgens/sq cm and 10^3 roentgens/sq cm (r/sq cm). Three types of plates were used:

1. 50-μ amorphous selenium layer on brass
2. 80-μ amorphous selenium layer on aluminum
3. 160-μ amorphous selenium layer on aluminum

The samples for exposure were arranged in the exposure plane and shielded from light.

Thermal neutron irradiation was performed in the pile of the Brookhaven National Laboratory. In this case, however, the consideration of residual radioactivity induced by neutron bombardment limited the exposure.

Since nuclear reactions occur with the base material as well as with the selenium, both components of the plate had to be considered. To avoid difficulties arising from induced radioactivity, only selenium plates with aluminum substrates were used for neutron exposure. Even aluminum will show some activity on removal from a pile, but this is shortlived and weak. Brass substrates cannot be used because of the presence of copper which becomes extremely radioactive. Glass substrates likewise are unsuitable because of the presence of sodium and boron.

Possible thermal neutron reactions with selenium were investigated. The most important one from the point of view of induced radioactivity was found to be the reaction:

$$Se^{74} + n = Se^{75} + \gamma$$

This determined the upper limit for exposure.

Three types of plates were employed:

1. 50-μ selenium layer on aluminum
2. 80-μ selenium layer on aluminum
3. 160-μ selenium layer on aluminum

Results

Gamma Irradiation

The results for both control and irradiated plates before and after γ irradiation are given in Table I.

TABLE I

Effect of Cobalt-60 γ-Irradiation on Selenium Xerographic Plates

Plate Identification Number	Description	V_0 (volts)	D_3 (%)	K_3 (%)	V_R (volts)	Irradiation r/(cm²)
1FBK945-4-1	50-μ Se on Brass	660	8	5	0	0 – Initial Properties
-2	"	600	5	--	0	1.3×10^5
-3	"	535	7	—	0	0 – Control
-4	"	580	9	—	0	0 – Control
-5	"	570	3	—	0	1.0×10^3
2FR465-7-1	80-μ Se on Al	640	5	5	90	Initial Properties
-2	"	710	1	—	100	1.3×10^5
-3	"	700	0	—	90	1.0×10^3
-4	"	700	1	—	70	0 – Control
-5	"	680	1	—	90	0 – Control
1FCN935-4-1	160-μ Se on Al	700	3	—	90	Initial Properties
-2	"	560	1	—	155	$1.3 \times 10^{5*}$
-3	"	575	1	—	130	$1.0 \times 10^{3*}$
-4	"	540	1	—	90	0 – Control
-5	"	565	1	—	90	0 – Control

* These data were obtained two days after irradiation.

The differences in V_0 (potential acceptance) arise from slight variations in charging conditions and are not significant. The only significant change occurs in samples of 160-μ layers of selenium. The residual potential of these irradiated samples was higher than that of the controls. However, they are not high enough to impair the image-forming quality of the plates.

Because the cobalt-60 source arrangement imposed a limitation on the size of the samples, fatigue measurement after the exposure could not be made. The absence of an increase in dark decay resulting from the exposure, however, can be taken as an indication that the plates experienced little, if any, fatigue.

Thermal Neutron Irradiation

The results for both the control plates and those irradiated with thermal neutrons are given in Table II. As in the case of γ-irradiation, the only notable changes occurred in the 160-μ selenium layers. Here, the increase in dark decay after irradiation is significant. The neutron exposure had no effect on the remainder of the samples, which had thinner selenium layers.

TABLE II

Effect of Thermal Neutron Irradiation on Selenium Xerographic Plates

Plate Identification Number	Description	V_0 (volts)	D_3 (%)	K_3 (%)	V_R (volts)	Irradiation (neutrons/cm^2)
VV 404-1	50-μ Se on Al	650	3	8	0	10^{13}*
-2	"	800	2	7	0	0 – Control*
-3	"	640	5	3	5	0 – Initial Properties
VV 405-1	50-μ Se on Al	690	0	38	0	10^{13}*
-2	"	620	6	30	0	0 – Control*
-3	"	620	6	30	0	0 – Initial Properties
UU 130-1	80-μ Se on Al	560	4	8	0	10^{13}*
-2	"	610	7	6	0	0 – Control*
-3	"	610	5	8	0	0 – Initial Properties
AAA540-1	80-μ Se on Al	535	7	17	0	10^{13}*
-2	"	600	7	11	0	0 – Control*
-3	"	580	6	7	0	0 – Initial Properties
2FCN451A-8-1	160-μ Se on Al	670	20	20	0	10^{13}*
-2	"	730	9	20	0	0 – Control*
-3	"	620	8	15	0	0 – Inital Properties

* These data were obtained one week after irradiation.

Discussion

These data show that no xerographically important damage was sustained by the irradiated selenium plates. The changes observed in the samples with thick layers of selenium would not seriously reduce their usefulness except in the most demanding applications.

It is possible to make a limited comparison of these results with the behavior of silver halide emulsions after nuclear irradiation. Early in 1957, the U.S. Army Engineering Research and Development Laboratories (ERDL) determined the effects of nuclear radiation on samples of photographic film and ZnO-binder type xerographic plates.[2] Samples of Kodalith Ortho Type II film and ZnO binder plates were packaged together and subjected to radiation from an atomic burst at the Nevada Test Site. Radiation exposure was varied by locating samples at different distances from the center of the burst and ranged from approximately 1.7×10^2 r/sq cm to 1.3×10^4 r/sq cm. Both the film and ZnO binder plates were evaluated after irradiation by means of test prints and by fog density measurements of the silver halide film. The following results were reported:

1. Kodalith Ortho Type II film was not usable after an exposure of 2.5×10^2 r/sq cm but was considered usable after an exposure of 1.7×10^2 r/sq cm.
2. The ZnO binder plates were not adversely affected after an exposure of 1.3×10^4 r/sq cm.

The highest cobalt-60 exposure to which the selenium plates were subjected in the present work was 10^5 r/sq cm, about one thousand times greater than the tolerance limit of the Kodalith Ortho Type II. Silver halide emulsions with larger grain sizes and higher speeds exhibit greater susceptibility to permanent radiation damage. In other experiments at the Stanford Research Institute,[3] it was determined that higher speed emulsions (Kodak Plus-X, Super-XX, and Tri-X) can tolerate only 5 roentgens of cobalt-60 radiation.

Conclusions

This work has shown that the usefulness of selenium xerographic plates is not significantly impaired by exposures to intense thermal neutron and cobalt-60 γ-radiations. The similar results obtained at ERDL with ZnO-binder type xerographic plates are corroborative and indicate the extreme stability of xerographic plates compared with silver-halide emulsion films.

References

1. Dessauer, J. H., Mott, G. R., and Bogdonoff, H., *Phot. Eng.*, *6:* 250 (1955).
2. *Nuclear Radiation Tests on Photographic Film and Binder Type Xerographic Plates*, USAERDL Memo File No. 8-35-09-112, 18 Oct. 1957.
3. *Manual of Weapons Effects Tests*, Stanford Research Institute For Field Command, Armed Forces Special Weapons Project, contract DA-29-044-XF-558, p. 75.

PHOTOGRAPHIC SCIENCE AND ENGINEERING
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Noise Spectrum of Developed Photographic Layers Exposed by Light, X-Rays, and Electrons

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The noise spectrum was measured for different photographic materials exposed by light, x-rays, and electrons. The $n(\nu)$ value for a particular material is constant over much of the measured space frequency range when exposures are made by light; it increases with increasing density. The $n(\nu)$ for x-ray and electron exposures, for prints, and for dye images formed by color development show the highest values for small ν and decrease with increasing ν; this result is explained by the formation of grain aggregates by the x-ray and electron exposures, as well as in making prints from the coarser-grain negatives, and by the formation of elements larger than the grains in color development by diffusion of oxidized developer.

Definition of Granularity as Related to the Standard Deviation or Noise Spectrum

The granularity of a photographic layer is often defined by the root mean square (rms) deviation of the density of a given area of a uniformly exposed and developed layer. Let the standard deviation be denoted by σ. The value of σ decreases with increasing area of the sample field (F) so that σ is inversely proportional to the square root of the measured area when the area is large in comparison to the statistically varying image elements. Let the density on a point of the sample (denoted by the vector $\vec{x}$ with the components x_1 and x_2) be $D(\vec{x})$ and let the mean density be $\bar{D}$. Then the fluctuation of the density is

$$\Delta(\vec{x}) = D(\vec{x}) - \bar{D} \qquad [1]$$

and the square of the standard deviation

$$\sigma^2 = \frac{1}{A} \iint_A [\Delta(\vec{x})]^2 \, dx_1 dx_2 \qquad [2]$$

(A = the investigated area of the sample)

The basic elements are composed of the individual silver grains in layers that have been exposed by light; and in such cases good correlation with the square root of the area exists already at values of $\sqrt{F} \approx 10$ to 20 μ. This correlation does not exist for areas of such small size when the exposure is made with x-rays or in prints, because the basic image elements are larger than one grain in these instances. In the case of x-ray exposures, several crystals are rendered developable by one quantum, whereas in printing the coarser structure of the negative is impressed onto the print image.

If the area of the elements is indicated by f, the following equation holds for $F \gg f$.

$$\sigma = 0.7 \sqrt{\frac{f}{F}} D$$

(D = density)

The granularity factor $G = \sigma\sqrt{F}$, which was proposed by Selwyn[1] has often been used in place of σ. (Here the Selwyn value is used without the factor $\sqrt{2}$, which was applied by Selwyn[1] and by Jones.[2]) G is independent of the sample area in the cases in which the standard deviation is inversely proportional to the square root of the sample area. A few examples of this are given in Fig. 1. It will be evident that within the test limits, G is independent of the sample area when the exposure is made to light, but that G increases as the sample area increases when the exposure is made to x-rays or when a print is involved. The granularity of the layers is adequately defined by the curves shown in Fig. 1 which represent G as a function of sample area.

Another method for defining granularity, proposed particularly by Jones,[2] involves the concept of the noise spectrum. The meaning of this concept can be elucidated in the following manner: When a small area of a layer that has been uniformly exposed and developed is scanned with a stationary light-sensitive microphotometer by moving the sample at a constant rate past the measuring aperture, one obtains an alternating current of varying frequency. The distribution of energy within the frequency bands con-

The work reported here was performed in the Research Laboratory of Agfa, Leverkusen, Germany. Results similar to those reported here have been obtained by an entirely different experimental procedure by H. J. Zweig of the Eastman Kodak Research Laboratories; see *J. Opt. Soc. Am.*, *49*: 238 (1959).

Presented at the Annual Conference, Rochester, N.Y., 9 October 1958. Received 14 April 1959.

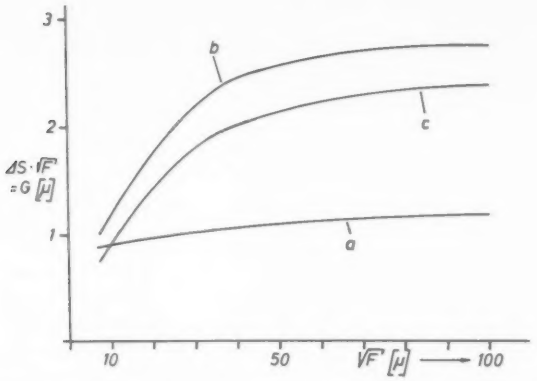

Fig. 1. The value of granularity G plotted against the square root of the scanning area for the layers. Curve a—Exposure to light; Curve b—Exposure to x-rays; and Curve c—A copy of a coarse-grain negative.

stitutes the frequency spectrum, which pertains to the spatial frequency ν, where ν equals the quotient of frequency per unit time, f and the velocity of scanning v, or $\nu = \frac{f}{v}$. The reciprocal of ν is the wavelength of the signal. The noise spectrum is obtained by Fourier transformation of the density fluctuation of the sample:

$$n(\nu) = \frac{1}{A}\left[\iint_A \Delta(\vec{x}) e^{-2\pi i \vec{\nu}\,\vec{x}} dx_1 dx_2\right]^2 \qquad [3]$$

Jones[2] has demonstrated that the standard deviation can be calculated if the filter function $u(\vec{\nu})$ of the measuring aperture is known,

$$\sigma^2 F = G^2 = F2 \int_{-\infty}^{+\infty}\int n(\vec{\nu})|u(\vec{\nu})|^2 d\nu_1 d\nu_2 \qquad [4]$$

For a circular aperture with radius a and an isotropic granularity, Jones obtained:

$$\sigma^2 F = G^2 = 2\int_0^\infty J_1^2(2\pi\nu a) n(\nu)\frac{d\nu}{\nu} \qquad [5]$$

For $n(\nu)$, Jones (Ref. 2 Eq. [10.2]) developed the following formula:

$$n(\nu) = \frac{\pi}{2.3}\delta^2 D(1-\tau)[J_1(\pi\delta\nu)/\pi\delta\nu]^2 \qquad [6]$$

where δ = diameter of the circular grains
D = density
τ = transparency of a grain
J_1 = Bessel function 1st order

Measurement of Noise and Noise Spectrum

The measurements were made with a photoelectric photometer which scanned a small area of the sample that was moved past the scanning aperture. A schematic diagram of this instrument is shown in Fig. 2. The sample was placed on a turntable that was mounted on a roller bearing of 25-mm inside diameter. The axis of rotation of this stage was parallel to the optical axis and was offset by 2 to 6 mm. It was important, of course, that the sample surface be perpendicular to the axis of rotation as nearly as possible, to minimize changes in focus during sample rotation. A continuously variable electric drive was used with which the speed of rotation

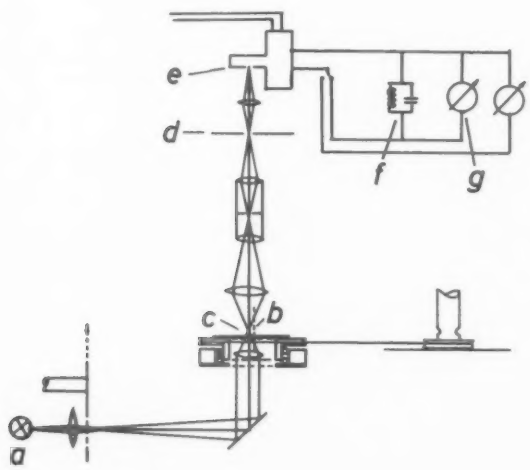

Fig. 2. Scanning apparatus.
a. Light source
b. Turn table
c. Sample
d. Slit
e. Photomultiplier
f. Electrical filter
g. Voltmeter

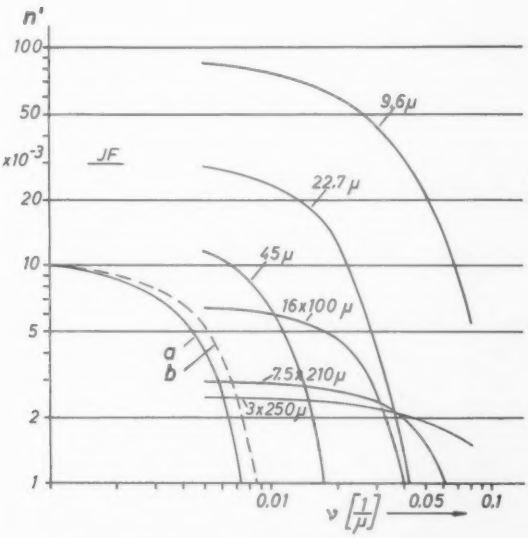

Fig. 3. The specific power spectrum $n'(\nu)$ measured with circular and rectangular apertures (density^2·μ^2). Contrast transfer function of a rectangular (a) and a circular (b) aperture.

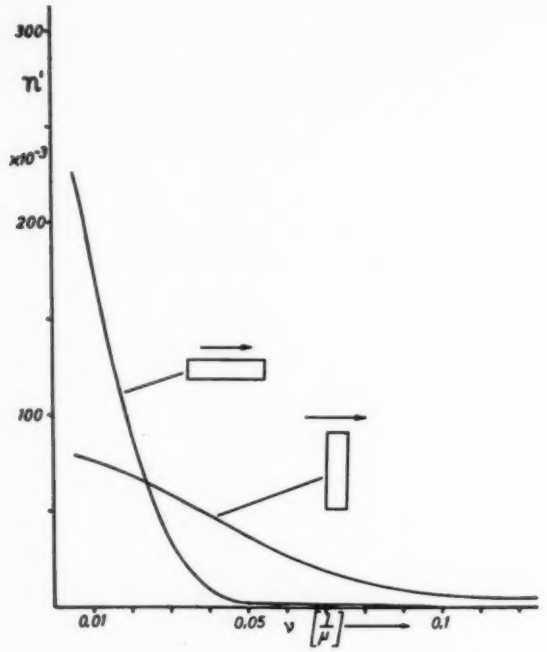

Fig. 4. The specific power spectrum $n'(\nu)$ measured with a slit of $7.5 \times 20\mu^2$ with different scanning directions (density$^2 \cdot \mu^2$).

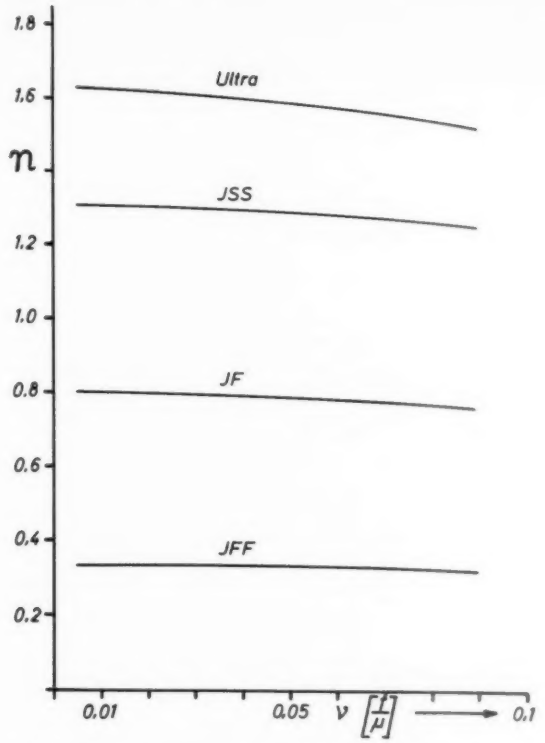

Fig. 5. Power spectrum of four layers with different granularity.

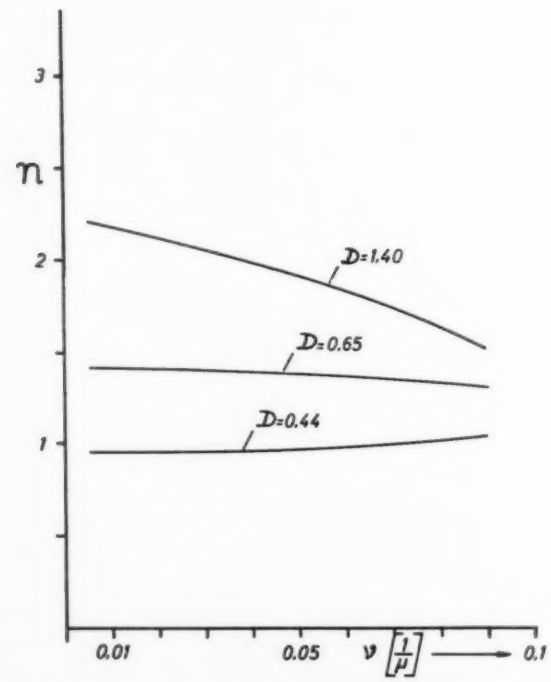

Fig. 6. Power spectrum of films with different diffuse densities.

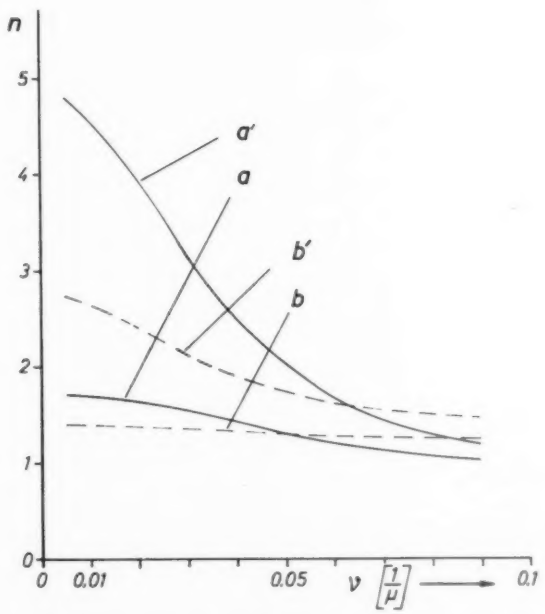

Fig. 7. Power spectrum for two films exposed with light (Curves a and b) and with x-rays (Curves a' and b').

could be set from 1.1 to 52 cm/sec. The rotational speed was measured stroboscopically. Measurements of the output must be made with an instrument capable of performing quadratic integration. A vacuum tube voltmeter which satisfied these conditions was used. Total current was measured for the determination of the standard deviation. It was important in these measurements that the performance of the amplifier which had to be used, as well as the performance of the voltmeter and of the cable, be independent of frequency within the required frequency band. When this condition is met, the noise spectrum is largely independent of the velocity with which the sample moves. The rotor speed was chosen to make the primary frequency fall within the low portion of the frequency-independent response region, since this insured transmission of the higher frequencies.[3]

For determination of the power-spectrum the noise current was analyzed with a frequency analyzer. However, most of the tests were carried out in the following fashion: A small range of frequencies, with a mean frequency of 950 Herz, was isolated for measurement by means of an electric filter connected in parallel with the output of the photomultiplier tube. The measured spatial frequency is then dependent on the scanning velocity $\left(\nu = \frac{f}{v}.\right)$ This permits evaluation of the noise spectrum through measurements made at different speeds of the sample.

Calibration of the test measurements was realized with the aid of a rotating sector which modulated the light incident on the photomultiplier.

If the layer is scanned in x_1-direction, the "specific noise spectrum," $n'(\nu_1) = 2\int_0^\infty |u(\vec{\nu})|^2 n(\vec{\nu}) d\nu_2$, will be obtained. $n'(\nu)$ is a function not only of ν_1 but also of the size and the form of the scanning area and of the direction of scanning.

$$\sigma^2 = \int_{-\infty}^{+\infty} n'(\nu) d\nu \qquad [7]$$

To obtain the noise spectrum $n(\nu)$, it is necessary to solve the integral equation.[5] This is shown for a slit by Jones.[2] $n(\nu)$ is independent of the scanning conditions and characterizes the granularity of the sample.

Figure 3 gives examples for $n'(\nu)$. The same layer is measured with three circular and three rectangular apertures and the results are plotted in logarithmic scales. In this case the curves for one kind of scanning area must be parallel to each other and also they must be parallel to the corresponding filter functions which are designated in the left corner. The effect of the direction of scanning is illustrated by Fig. 4. Here a sample is scanned with a rectangular aperture, one in direction of the long side and the other one in direction of the narrow side. $n'(\nu)$ reaches zero if ν is equal to the inverse value of the dimension of the rectangle in the direction of scanning.

Results of the Noise Spectrum Measurements

The results of these measurements are summarized in Figs. 3 to 7. $n(\nu)$ is indicated in [density^2 μ^2] (see Ref. 3).

Light Exposure

It will be noted from Figs. 5 and 6 that $n(\nu)$ is constant over much of the measured region when exposures are made by light. The differences between various films are clearly evident in Fig. 5. These differences are particularly great since $n(\nu)$ varies as the square of the density fluctuation. The effects of variations in density for a given film are illustrated in Fig. 6. As might be expected, $n(\nu)$ increases in this case with increasing density and is proportional to the density, as is readily apparent. The constant value of $n(\nu)$ within the measured region of ν values is in agreement with the formula of Jones (Ref. 2, Eq. [10.2]—Eq. [6] of the present paper).

Exposure with X-Rays or Electrons

Within the investigated range of ν, $n(\nu)$ shows higher values in the case of x-ray exposures when ν is small and decreases rapidly as ν becomes greater (Fig. 7).[4,5] Evidently the individual silver grain is no longer the basic image element in this instance, but rather aggregates of silver grains which are formed by the incident x-ray quanta. At high frequencies, however, the values are about the same as for light exposure; in this region the fluctuations are caused by the individual silver grains. The aggregates affect the measurements only at the lower frequencies. Exposure with electrons yields results that are similar to those obtained with x-rays.

It may be pointed out that the power spectrum for exposures with electrons (n_E) is approximately equal to the sum of the power spectrum of single grains (n_G) and of the aggregates (n_A). For electrons, the following equation holds approximately[5]:

$$n(\nu) = \frac{\pi}{2.3} D\delta_K{}^2 \left\{ \psi \left[\frac{J_1(\pi\nu\,\delta_A)}{\pi\nu\delta_A} \right]^2 + \left[\frac{J_1(\pi\nu\,\delta_K)}{\pi\nu\delta_K} \right]^2 \right\} \qquad [8]$$

D = density
δ_K = diameter of grains
δ_A = diameter of aggregates
ψ = number of developed grains for one incident electron
J_1 = Bessel function, 1st order

Prints

In this case, the $n(\nu)$ values approximate those determined for x-ray exposure. Grain aggregates are formed again, but they are outlines of the coarse structure of the original image impressed onto the fine-grain print film. At high frequencies, only the $n(\nu)$ values of the print film are measured, in effect, and the structure of the original image is not transferred. This happens because at the high frequencies

light diffusion and loss of sharpness have such a pronounced deleterious effect that the original image is reproduced only at very reduced contrast. As a matter of fact, one could think of making such measurements for the determination of the contrast transfer factors of print materials. At low frequencies, much higher values of $n(\nu)$ are obtained than would be expected from the $n(\nu)$ values of the original image. The explanation for this is evident from Fig. 8. This magnification of $n(\nu)$ values is particularly great when the density of a print falls within a region of steep gradient (g) of the print material. The shape of the $n(\nu)$-curve is in good agreement with the appearance of the print image. One sees essentially large elements which are considerably larger than the individual grains of the original image. The size of these elements is about 50 μ as can be determined from the curves of Fig. 8.

Color Films

The results obtained in a color developing (magenta) test are shown in Fig. 9. Here, after development, one time the dye has been bleached and the other time the silver. Then n values for the silver image plot nearly horizontally, whereas, the values of the dye image again show the marked decrease noted before. This indicates that larger elements are formed also in color development. They occur as a result of diffusion of oxidized developer products from the grain to neighboring areas and subsequent color coupling. In this manner, areas of high dye concentration sites now represent the image elements. On the basis of the curve shown in Fig. 9, the diameter of the elements is judged to be near 30 μ.

The values of the power spectrum are so much smaller for the silver image ($n_{Ag}(\nu)$) than for the dye image ($n_F(\nu)$) because the density of the former (D_{Ag} = 0.45) was much lower than the red density of the dye image (D_F = 1.33). It is possible to compute the power spectrum of the silver image that would be obtained at the density of the dye image by multiplying $n_{Ag}(\nu)$ by $\left(\frac{D_F}{D_{Ag}}\right)^2$. Curve C of Fig. 9 was obtained in this manner, and verifies the statement made previously. Curve C matches Curve B (color image) rather well for small values of ν. The reproduction of these frequencies is not affected by the dye development. However, B falls pronouncedly with respect to C at high frequencies; in other words, the reproduction of high frequencies suffers as a result of the spreading of the dye.

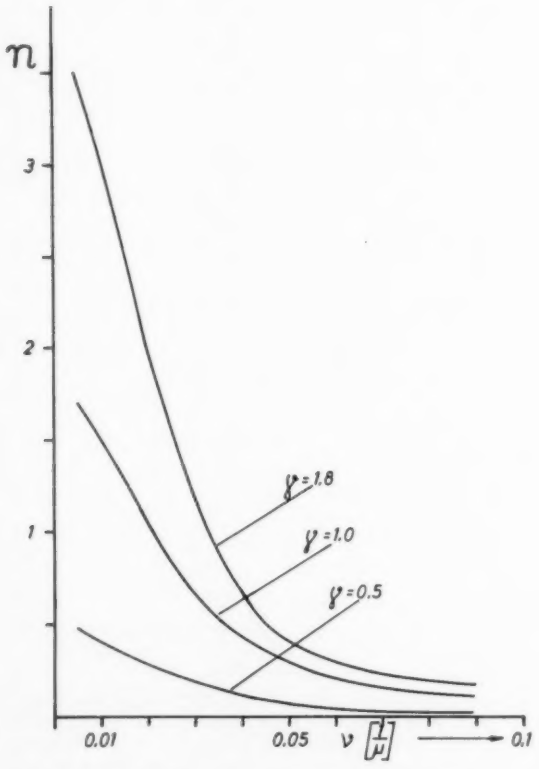

Fig. 8. Power spectrum of copies printed with different γ-values.

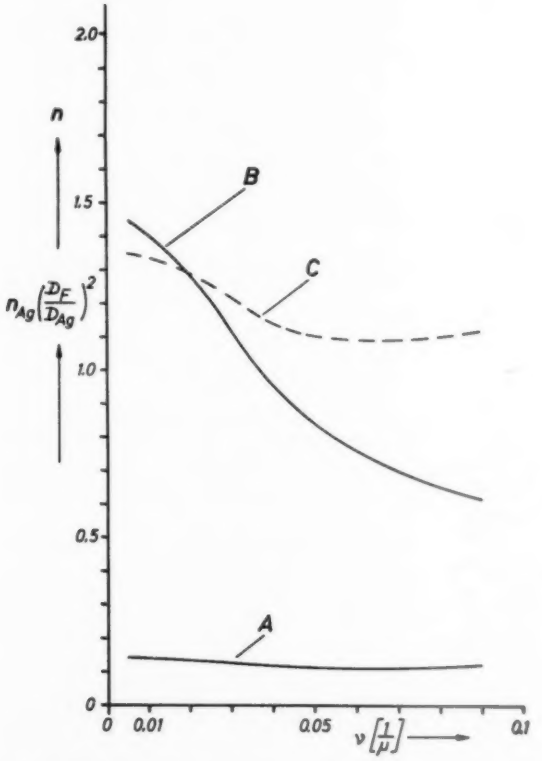

Fig. 9. Power spectrum of color films. Curve A—Silver image alone (n_{Ag}); Curve B—Dye image alone; Curve C—$n_{Ag}\left(\frac{D_F}{D_{Ag}}\right)^2$

Calculation of the Value of G

It is feasible to compute the values of σ and G from the power spectrum. The necessary integration is best carried out graphically. As may be seen in Table 1, good correlation is obtained between the values computed in this manner and those determined by direct density measurements. This applies not only to light-exposed images which have practically constant values of $n(\nu)$, but also for x-ray exposures and prints whose $n(\nu)$ values decrease markedly.

TABLE I

Sample	Scanning aperture (diameter)	G (density micron) determined by use of: Measurement of densities μ	$n'(\nu)$ [7]	$n(\nu)$ [3]
Isopan Ultra	22.7	1.11	1.12	1.26
	46	1.06	1.06	1.27
Isopan SS	22.7	1.09	1.11	1.09
	46	1.18	1.30	1.10
Isopan F	22.7	0.80	0.80	0.88
	46	0.77	0.73	0.89
X-ray film, exposed by x-rays	22.7	1.81	1.99	2.20
	45	2.52	2.16	2.50
Copy Ultra on positive	22.7	1.53	1.83	1.70

Conclusions

The results of this study indicate that the power spectrum is a valuable means for evaluating granularity of photographic emulsions. While it is practicable to define the granularity of images produced by light exposure with a single number, it is necessary to utilize the power spectrum or one of its derivative functions for defining the granularity of images formed by x-ray or electron exposures, or by printing and color development. The application of the power spectrum analysis is not restricted to the examples cited here, and there is great interest in the evaluation of contact and projection prints made on photographic paper, including color paper, and of images formed by reversal processing. It might be well also to study the influence of the surface characteristics of papers by this method. Many other applications suggest themselves in the graphic arts field.

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Normalized Acutance as a Criterion for Testing Photographic Lenses

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It is shown on theoretical grounds that normalized acutance yields a valid and useful method of rating lenses for edge sharpness. Normalized acutance is defined as the mean square density gradient on the film divided by the square of the total density difference. An experiment is reported which confirms the theory and gives an indication of the accuracy limit of an acutance determination.

In 1952 G. C. Higgins and L. A. Jones introduced the concept of acutance as the objective correlate of the subjective, psychophysical phenomenon of edge sharpness.[1,2] Figure 1 shows the relationship between photographic density and distance on the photographic image of a perfect edge. Higgins and Jones[1,2] and Higgins and Wolfe[3] found that acutance is best expressed by the mean square density gradient (of the density vs. distance plot in the transition zone between high and low density on a film) divided by the density scale. This concept can be expressed mathematically, using small, finite differences rather than differentials, as

$$A = \frac{1}{S_D}\frac{1}{n}\sum_{i=1}^{n}\left(\frac{\Delta D}{\Delta x}\right)_i^2 = \frac{\overline{G_x^2}}{S_D} \qquad [1]$$

where D = density
S_D = density scale
x = distance
Δ = an operator indicating an increment
n = number of distance increments taken between threshold limits (such as A and B in Fig. 1), determined by Higgins and Jones, such that $\Delta D/\Delta x = 0.005$ in density/micron.

All Δx's should be equal and as small as is experimentally convenient. The magnitude of x, together with the threshold value, will determine n.

The primary purpose of these earlier studies was to provide a means of rating films; however, an extension of the concept to permit rating of lenses would certainly be useful in cases where the major interest is edge sharpness or over-all picture definition. It is obvious that any such rating for lenses must be independent of the film and development characteristics, as well as total exposure, since variations in any of these do not affect the intrinsic properties of the lens. It is the purpose of this paper to show that normalized acutance, defined as

$$A_n = \frac{1}{n(S_D)^2}\sum_{i=1}^{n}\left(\frac{\Delta D}{\Delta x}\right)_i^2 = \frac{\overline{G_x^2}}{(S_D)^2} \qquad [2]$$

is a measure of the ability of a lens to reproduce edges. For reasons which are explained below, the constant n is now taken as the number of increments between threshold limits of 0.005 in density/micron divided by the density scale.

Theory

It is desired to study the rating of a lens by its ability to reproduce a perfect edge. It will be assumed that the fidelity of reproduction of a film is much higher than that of a lens. The acutance of a lens-film combination will then be considered to be the acutance of the lens alone. It will also be assumed that all photographic processes are controlled in such a manner that the density on a photographic film can be related to the energy incident on the film by the familiar expression

$$D = \gamma \log (E/E_0) \qquad [3]$$

where γ and E_0 are well-known photographic constants and E is the incident energy per unit area.

A lens images a perfect edge in such a way that the energy on the focal plane is related to the distance along the focal plane, perpendicular to the edge, by the relationship

$$E = a + bf(x) \qquad [4]$$

where a and b are constants and $f(x)$ is an arbitrary function subject to the following restrictions:

1. When $x = 0$, $f(x) = 0$.
2. When $x = \infty$, $f(x) = 1$.
3. $f(x)$ is independent of a and b.

Figure 2 shows these conditions graphically.

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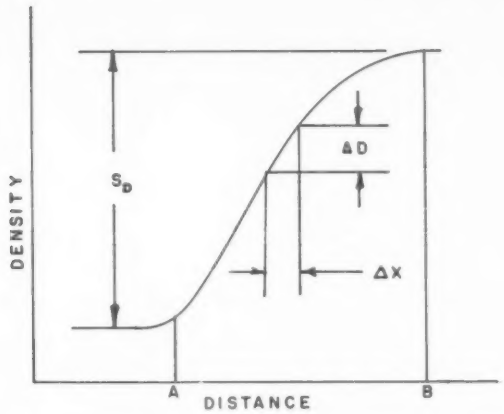

Fig. 1. Density of the negative vs. distance along a photograph of a knife edge.

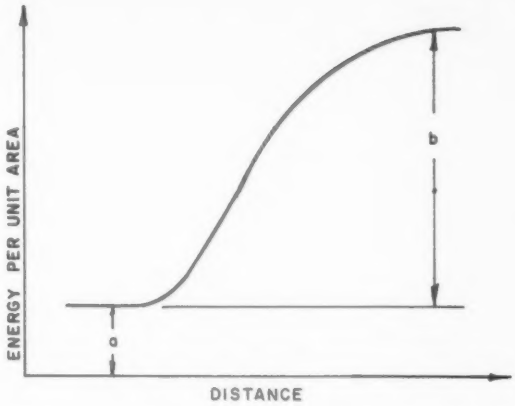

Fig. 2. Energy per unit area incident on the film plane vs. distance along an image of a knife edge.

We shall now attempt to show that, under usual conditions, normalized acutance is independent of development and exposure parameters. First let us see what effect there will be if we change the development parameters γ and E_0 to γ' and E_0'. From Eqs. [3] and [4]

$$D = \gamma \log (E/E_0) = \gamma \log \left[\frac{a + bf(x)}{E_0}\right] \quad [5]$$

Substituting γ' for γ and E_0' for E_0

$$D' = \gamma' \log \left[\frac{a + bf(x)}{E_0'}\right] \quad [6]$$

where D' refers to the density value that results from use of the new constants.

Differentiation of both Eqs. [5] and [6] with respect to x yields the following results:

$$\dot{D}'/\dot{D} = \gamma'/\gamma \quad [7]$$

for any value of x. The dot $(\cdot)$ refers to differentiation with respect to x.

From the definition of S_D given in Fig. 1, and from Eq. [3],

$$S_D'/S_D = \gamma'/\gamma = \dot{D}'/\dot{D} \quad [8]$$

The mean square density gradient is then

$$\overline{G_x^{2'}} = \frac{1}{n'} \sum_{i=1}^{n} \left(\frac{\Delta D'}{\Delta x}\right)_i^2 = \left(\frac{S_D'}{S_D}\right)^2 \frac{n}{n'} \overline{G_x^2} \quad [9]$$

From Eq. [8] $\dot{D}'/S_D' = \dot{D}/S_D$ for any value of x. Thus it can be seen that the threshold values of the gradient (defined as $0.005/S_D$ per micron) will occur at the same values of x for both curves, and therefore $n = n'$.

One can then write

$$\frac{\overline{G_x^2}}{(S_D)^2} = \frac{\overline{G_x^{2'}}}{(S_D')^2}$$

or $A_n' = A_n$, where A_n is defined as normalized acutance.

Thus, for densities on the straight portion of the density vs. log exposure curve, normalized acutance is independent of the constants of development.

Now let us investigate the effect of changes in both exposure and development. Assume that a, b, γ, and E_0 are changed to a', b', γ', and E_0'. Using the same derivation as that employed above for the case of development changes only, we have

$$\dot{D}' = \frac{\gamma' b' [a + bf(x)]}{\gamma b [a' + b' f(x)]} \dot{D} = \frac{\gamma' \left[\frac{a}{b} + f(x)\right]}{\gamma \left[\frac{a'}{b'} + f(x)\right]} \dot{D} \quad [10]$$

In the same fashion, for this case

$$S_D'/S_D = \frac{\gamma' \log \left[\frac{(a' + b')}{a'}\right]}{\gamma \log \left[\frac{(a + b)}{a}\right]} = \frac{\gamma' \log \left(1 + \frac{b'}{a'}\right)}{\gamma \log \left(1 + \frac{b}{a}\right)} \quad [11]$$

If $b/a = b'/a'$ (i.e., if the two targets have the same constrast), Eqs. [10] and [11] reduce to Eq. [8] and it is again possible to say that

$$A_n' = A_n$$

Thus the normalized acutance is also independent of the absolute values of the exposure constants a and b, so long as these points remain on the straight line portions of the density vs. log exposure curve.

Experimental Confirmation

Five spectroscopic plates were exposed with the target shown in Fig. 3 and the experimental setup shown in Fig. 4. Each plate contained ten exposures, each of which differed from the next by a log exposure

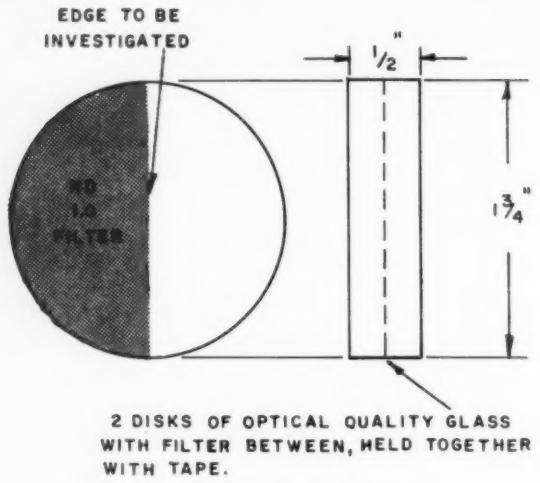

Fig. 3. Acutance test target.

difference of 0.2. Each plate was developed for a different time in Kodak D-76 developer at 70°F. The normalized acutance was calculated for those exposures which fell on the straight line portion of the density vs. log exposure curve.

A Jarrell-Ash recording microphotometer was used to determine the edge trace, and computations were made with a Burroughs E102 electronic digital computer. No curve-smoothing was attempted in the calculations. Limits of accuracy of the acutance determination are between 10 and 20%.

▶ Table I summarizes the results of the experiment. Over the range of development times used, the density difference for the longest time was 2.8 times as great as that for the shortest. The $\overline{G_x^2}$ varied markedly, while the normalized acutance remained essentially constant. The lower exposures, obtained by means of increased filtration, exhibited slightly lower normalized acutances. The reason for this was that there was a slight fogging caused by extraneous light and flare light. The result was to decrease the contrast. This phenomenon is more important at the lower exposures.

TABLE I
Summary of Normalized Acutance Test

Development time	ND Filter	$\overline{G_x^2}$	A_n	n	S_D	Average A_n
1:15	2.0	123	206	25	0.770	
	2.2	99	189	26	0.721	190
	2.4	88	175	26	0.710	
1:40	2.0	321	255	22	1.122	
	2.2	290	224	25	1.138	218
	2.4	221	198	26	1.058	
	2.6	172	195	26	0.939	
2:15	2.0	507	246	24	1.433	
	2.2	485	206	27	1.533	216
	2.4	512	219	25	1.527	
	2.6	404	192	26	1.451	
2:50	2.4	692	210	24	1.809	192
	2.6	532	173	27	1.751	
3:30	2.4	987	256	23	1.965	230
	2.6	830	203	25	2.018	
Mean			203	25		
Standard deviation			13%	5.4%		

Discussion

It is obvious that changing the density threshold from a constant to a function of the density scale was a crucial step in arriving at our result. The question which is legitimately asked is, "How does changing the threshold affect (normalized) acutance as a measure of the visual appearance of sharpness?" The answer can be found in the following hypothetical experiment:

(1) Perform an experiment identical with the one reported here with the exception that a series of lenses is tested and the resultant negatives are all developed to the same density scale (other than 1.0). By performing all the tests at the same S_D, it is no longer important whether we divide $\overline{G_x^2}$ by S_D or S_D^2.

(2) Consider the case where S_D is greater than 1.0. (The same reasoning will hold for $S_D < 1.0$.) If we compute acutance based on a threshold of $\Delta D/\Delta x = 0.005/S_D$/micron, we will find that the values we obtain for all the lenses will be less than those we compute based on a threshold of 0.005/micron.

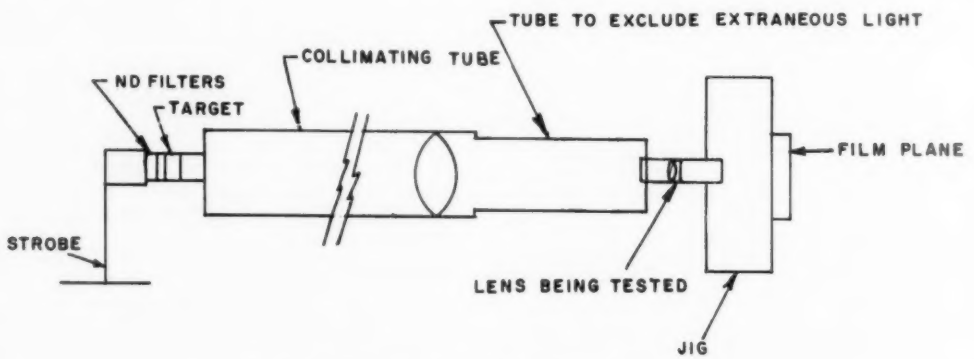

Fig. 4. Schematic of experimental setup for lens test program.

However, we will find that since the toe and the shoulder of the density vs. distance curve for one lens is quite similar in form to that of almost any other lens, and since the range of useful density contrast is usually in the rather limited range of 0.5 to 2.0, the order in which the lenses rank will rarely change.

(3) Note that since a lens rating rarely has much value except as a comparison with other lens ratings, the difference caused by changing thresholds is, for most practical purposes, largely academic.

Another rather interesting question is, "What is the relation between acutance and normalized acutance for a given lens?"

It is immediately obvious that, neglecting threshold effects, the acutance of a negative is directly proportional to the product of the normalized acutance of the lens and the density scale of the negative.

$$A = A_n S_D$$

This confirms the intuitive feeling that the apparent sharpness of a picture exposed through a given lens should increase as the contrast of the negative is increased.

Acknowledgment

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Conditions for Projection Copying on Dye Cyanide Sensitized Materials

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In order to explore the possibilities of projection copying of printed matter upon a print-out photographic material sensitive only to the ultraviolet, measurements have been made of the order of contrast and printing speed that might be expected. The conclusion is reached that with a lens transmitting the ultraviolet region of 2800 – 3200 A and operating at f/4, projection prints could be made by exposures of a fraction of a minute by radiation from commercial mercury lamps.

A rapid and cheap method for copying from books would extend the usefulness of libraries. The following work was done on a contract from the Council on Library Resources, Inc., to survey the conditions that would be encountered in trying to develop a copying process based on the use of printing-out materials sensitive only to ultraviolet. If sufficiently short printing time and sufficiently high contrast could be attained, such a method would offer the advantages of making immediate prints without chemical processing which would be sufficiently stable for casual indoor use and storage, and which could be protected from fog under stronger illumination, including full sunlight, by a film of colorless, transparent, ultraviolet absorbing plastic.

To appraise the feasibility of such a process measurements were made of the reflectance of American book papers at two regions of the ultraviolet, and an elementary sensitometric study of a representative dye cyanide sensitized photographic material was carried out. Relations between the intensity of irradiation of the original and the exposure required to make a satisfactory projection print were established. This paper does not go into the problem of development of ultraviolet transmitting lenses.

Ultraviolet Reflectance of Book Papers

W. J. Barrow,* who has made a study of book papers, kindly supplied me with samples of twenty-seven papers from his collection. These were stated to include the papers used in the great majority of books printed in America today.

A pad four sheets thick of each of the 27 papers was mounted on a board and irradiated normally by a 4-w germicidal lamp located 8 in. from the paper. At the paper surface the intensity of the 2537 A radiation was approximately 230 μw/sq cm.

At an angle of 45° from the plane of the paper the diffuse reflectance was measured by a photometer equipped with a No. 935 phototube. Reflectance standards were aluminum plates freshly smoked with magnesium oxide.

Measurements were made of (1) the unfiltered reflectance, (2) the reflectance filtered through a Corning No. 9700 glass filter which absorbed 2537 A completely but transmitted freely the mercury spectrum of wavelengths longer than 2900 A, and (3) the reflectance through the Corning No. 9700 glass combined with a Corning No. 9863 glass filter. The combination transmitted the mercury lamp spectrum in the region from 2900 A to 4000 A but absorbed all the rest to which the phototube was sensitive. In measurements (2) and (3), only the reflected radiation was filtered; the radiation incident on the papers was unfiltered.

The reflectance of the mercury line of 2537 A was obtained by subtracting from the total reflectance that measured through the No. 9700 filter increased by 10%, 10% being the measured reflection and absorption of the filter itself for wavelengths longer than 2900 A. The logic of this procedure follows from the consideration that, while about 95% of the radiation from the germicidal lamp lay in the 2537 A line, the papers selectively reflected more of the 5% of longer wavelength radiation, and the phototube also was more sensitive to the longer wavelengths. Therefore, to isolate the effect of the 2537 A line on the photometer, the effect of the total of this line and the longer wavelength radiation was reduced by the amount of the photometric effect of the longer wavelength radiation.

The diffuse reflectance of 2537 A by the book papers ranged from 11% to 36% of that from a fresh magnesium oxide film. The median value was 18%. The diffuse reflectance of the low-pressure mercury arc radiation in the range from 2900 to 4000 A ranged from

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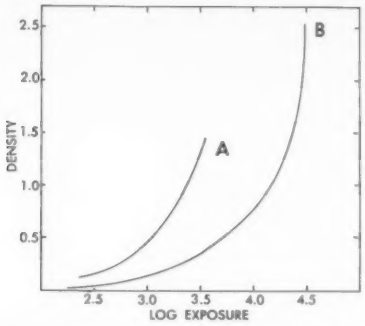

Fig. 1. Curve A — materials printed by 2800 – 3200 A. Curve B — materials printed by 2537 A. Exposures measured in microwatts per square centimeter seconds.

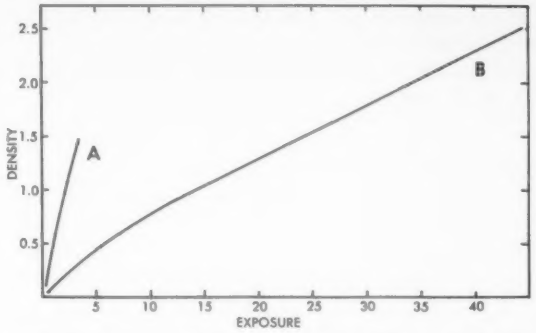

Fig. 2. Curve A — materials printed by 2800 – 3200 A. Curve B — materials printed by 2537 A. Exposures measured in milliwatts per square centimeter seconds.

21% to 72% of the reflection from magnesium oxide. The median value was 40%. Comparable values for Eaton Dikeman 48-lb No. 646 filter paper were 53% reflectance of 2537 A and 72% reflectance of the 2900 A to 4000 A heterogeneous mercury arc radiation.

Two of the papers contained fluorescent brightening agents which increased the reflectance of the 2900 — 4000 A region above what would have been obtained if the incident radiation had been filtered. However, the increase was not sufficient to bring the reflectance of either of these papers to the maximum value found among the other papers.

It was found that different sheets of the same brand and grade of book paper might vary considerably in ultraviolet reflectance. Therefore the significance of the data on the papers is primarily statistical.

Measurements were made in the same way of the diffuse reflectance of the principal types of black printing ink (offset, halftone, bond, antique, news) applied to appropriate papers.* The diffuse reflectance of 2537 A by these inks ranged from 0.5 to 2.3 % of that of magnesium oxide. For the 2900–4000 A region the reflectances ranged from 0.4 to 2.6% of that of magnesium oxide. Because of the large number of possible combinations of commercial black printing inks with available papers, and because the final impression from even a single combination of ink and paper can be varied by the way in which the printing is carried out, a more constant and generally available standard for black was found in the matt black paper packed between sheets of photographic cut film. When compared with magnesium oxide this reflected 3.9% of 2537 A and 3.5% of the heterogeneous 2900 –4000 A region. Thus its diffuse reflectance was greater than that found for any of the printing inks, and its adoption as the black standard led to conservative estimates of contrast between the reflectance of the papers and printed areas.

* Printing ink samples kindly supplied by the Printing Ink Division of the Interchemical Corporation.

Photosensitive Material

The printing-out materials used in this work employed dye cyanides as the photosensitive element. A number of these sensitizers are known. They may be used in a variety of photosensitive systems and a range of concentrations.[1–3] They print out fully formed negative images on exposure to ultraviolet radiation, obey the reciprocity law and have an indefinite shelf life.

Glass plates coated with a transparent film containing 2 mg of aurine cyanide per square inch in an alkaline medium[4] were used for measurement. This sensitizer was chosen because it could be used in transparent films and in various types of coated papers, and because it printed an image with an absorption maximum near the green mercury line, 5461 A, and so lent itself readily to density measurement by monochromatic light.

Geometric series of exposures were made upon the plates by 2537 A radiation from a germicidal lamp and by the group of mercury lines 2890-3132 A, inclusive, emitted by an S4 mercury arc sun lamp. Densities of the images, measured against the unexposed plate, were photometrically determined by 5461 A light. The exposures to 2537 A were made at a constant intensity of 70 μw/sq cm, and those to the sun lamp at a constant intensity of 44 μw/sq cm.

When plotted against the logarithm of the exposure, the densities did not produce a straight line at any value up to the maximum of 2.5 that was measured. The curves are shown in Fig. 1. However, the relation of exposure to density was nearly linear, as shown in Fig. 2. Exposure was measured in microwatts per square centimeter seconds.

It will be observed from Fig. 1 that the image printed more slowly by 2537 A than by the 2800–3200 A band. By 2537 A the energy required to print a density of 0.1 was 900 μw/sq cm sec, while for the 2800–3200 A band the exposure to print a density of 0.1 was 200 μw/sq cm sec.

The decreased sensitivity at the shorter wavelength is not an inherent property of the dye cyanide sensitizers, but may be caused by selective absorption of

other components of the photosensitive system, such as the film-forming colloid. Some colloids, such as gelatine, which produce films having desirable mechanical properties exhibit a considerable increase in absorption in the shorter wavelengths. When paper is sensitized by impregnation without the use of a film-forming colloid, the materials may be quite as sensitive to 2537 A as to the 2800–3200 A band. However, because of the size of the paper fibers, such materials are not suitable for high-resolution images.

The aurine cyanide sensitized film was sensitive to wavelengths shorter than about 3200 A. It was not at all sensitive to longer wavelengths and, in common with most of the dye cyanide sensitized products, did not fog when exposed for hours to sunlight behind such colorless glasses as the Corning Glass Company's Nos. 3060, 3850, and 7380, or colorless ultraviolet absorbing films, such as Celanese Color No. L 419, gauge 0.0075.* The print on the aurine cyanide sensitized material could be handled and used for some purposes under ordinary indoor illumination without noticeable fogging. It could be completely protected from fogging under intense illumination by covering with one of the colorless ultraviolet absorbing glasses or films.

Relation Between Radiation and Image Intensities

A new 15-w germicidal lamp which had an intensity at 13 cm of 1200 μw of 2537 A per sq cm was placed at an angle of 45° and 13 cm from the center of a target of book paper having the median reflectance of 18%. Normal to this paper at twice its focal length of 93 mm was placed a simple plano convex fused quartz lens having an aperture of 48 mm, and thus workign at approximately $f/4$. In the plane of the full-sized image, the intensity of 2537 A was 2 μw/sq cm. Energy measurements were made by actinometers.[1] The energy ratio of 1:600 was about what would be expected from geometrical considerations and the reflectance of the paper.

The lamp was replaced by an S4 mercury lamp that had been burned for some hundreds of hours and radiated at 25 cm from the center of the lamp 210 μw/sq cm in the mercury lines 2890–3132 A, inclusive, to which the aurine cyanide material was sensitive. The paper target was changed to one having the median reflectance of 40% in the 2900–4000 A region, and its center placed 25 cm from the lamp center. The quartz lens was changed to twice its best focal length of 96 mm for this radiation. In the plane of the full-sized image the energy in the 2890–3132 A band was 0.5 μw/sq cm. The ratio of 1:400 is less than would be expected from a paper having a reflectance of 40%, corresponding more nearly to 30%. The difference is not unusual because the reflectance was measured over the spectral range of the mercury arc from 2900 to 4000 A, whereas the energy ratio was determined only for the short wavelength end of this region, where the reflection was less than at the long wavelength end of the region.

Ultraviolet Lamps

A variety of lamps are used to supply ultraviolet radiation, such as the cored carbon arcs, the hydrogen and xenon discharges and the mercury arcs. The latter are cleaner and require less attention than the carbon arcs, are commercially available in a variety of styles and sizes, and are cheaper than the hydrogen and xenon lamps per watt of radiation. They fall into three classes: the photochemical lamps which radiate all of the ultraviolet mercury spectrum transmitted by fused quartz; the cold, low-pressure, mercury arcs which radiate primarily the 2537 A line; and the sun lamps which, in the range of spectral sensitivity of the aurine cyanide plates, radiate the lines 2890 to 3132 A, inclusive, or, in the case of the fluorescent sun lamps, a continuous band within this spectral region. All could be used for copying, and the choice between them would depend on energy requirements, permissible spectral range, accessory equipment, warm-up time, ozone production, etc.

Discussion

From the reflectance data, it is apparent that the pages of books would reflect relatively more energy and have greater contrast between the paper and the printing for the spectral region around 3000 A than for that around 2500 A. The use of the shorter wavelength has one possible considerable advantage in that it is available from lamps giving practically monochromatic radiation and therefore would not require a chromatically corrected lens. If an achromatic lens were available advantages would seem to lie in the use of the 2800 – 3200 A region, or this combined with the shorter wavelength mercury lines if more energy is needed than can be obtained from the sun lamp types.

Because the density of the printed out image is approximately proportional to the exposure, the time of exposure required to produce a given density of image viewed as a print, i.e. against a reflecting white background, is about half of that required to give the same density in a transparency in which the light for viewing passes through the image only once. Therefore, the use of paper prints, rather than of films to be viewed as transparencies, would effect a material reduction in printing time.

The density required in an image strong enough to be read easily without strain probably varies with the color. For the pink image printed by the aurine cyanide sensitizer a density of 0.6 to 0.8 as measured by 5461 A would seem desirable, although lower densities are quite visible. Further considerations will be based on an image density of 0.8 as obtained in a print-on paper.

The contrast to be expected in a print with a density of 0.8 may be estimated from the data on book paper reflectance and printing characteristics of the photo-

* Film kindly supplied by the Celanese Corporation of America, 744 Broad St., Newark 2, N.J.

sensitive material. The paper with the median reflectance in the 2900–4000 A region was estimated to have a reflectance at 2800–3200 A of about 30%. A matt black paper had a reflectance of about 3.5%, which may be used as a measure of the fog to be expected in a line print. Therefore, when the image of the white paper with 30% reflectance had printed to a density of 0.8, the image of the black lines would also print to a density corresponding to an exposure of 3.5/30 times the exposure required to print a density of 0.8. This density, determined from the data of Fig. 2, would be less than 0.1, and the contrast should be quite adequate for reading. The stark black-and-white contrast of line prints is not necessary for legibility.[5]

To check this deduction a plate that would print to a density of 0.8 when viewed against a white background by an exposure of 20 sec was fogged by an exposure of 2½ sec, then placed behind a stencil and given an additional exposure of 17½ sec. The resulting contrast was entirely satisfactory for reading.

From these considerations it appears that photographic copying from books by middle ultraviolet radiation would require printing of an image with a minimum density of 0.6 to 0.8. By mercury arc radiation in the 2800–3200 A range a density of 0.8 printed through an $f/4$ lens from an average book paper would require on aurine cyanide sensitized paper an exposure of 830 μw/sq cm sec (the exposure that would print a density of 0.4 on a transparency). If an exposure time of 1 min were set, then the intensity of radiation in the beam from the lamp where it impinged on the printed page would have to be $830/60 \times 400 = 5530$ μw/sq cm. There are a number of commercial mercury arc lamps capable of this output.[6]

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1. Chalkley, L., *J. Opt. Soc. Am.*, *42:* 387 (1952).
2. ———, *J. Am. Chem. Soc.*, *77:* 1848 (1955).
3. ———, U.S. Patents, 2,676,887; 2,829,148; 2,829,149; 2,829,-052; 2,839,542; 2,839,543; 2,844,465; 2,855,300; 2,855,303; 2,855,304; 2,864,751; 2,864,752; 2,864,753; 2,877,166; 2,877,-167; 2,877,168; 2,877,169.
4. *Cf.* ———, U.S. Patent 2,855,303, Example 19, which describes a similar though not completely transparent material.
5. Stevens, G. W. W., *Microphotography*, John Wiley & Sons, New York, 1957, p. 250.
6. *E.g., see* Weitz, C. E., *General Electric Lamps*, Application Engineering Bul. LD-1, General Electric Company, Cleveland 12, Ohio, Jan. 1956, p. 50.

• Notes from the Editor

Technicalia Photographica

Frank Smith's section is unavoidably absent from this issue. The next issue will carry it as usual.

Personal Notes

N. F. Mott, Cavendish Professor of Experimental Physics at the University of Cambridge, England, and co-author of the Gurney-Mott mechanism of latent image formation, has been elected Master of Gonville and Calus College, Cambridge, to succeed Sir James Chadwick.

Ralph M. Evans, director of the Color Technology Division, Eastman Kodak Co., received the Godlove Award of the Inter-Society Color Council at the banquet held in New York City on April 1 during the Council's annual meeting. The award is presented biennially to a person selected for outstanding "contributions to the knowledge of color."

Carsten Th. Dubber has been appointed Member of the Board and named General Sales Manager of Zeiss Ikon Ag., Stuttgart.

British Standards

The first two British Standards in a series for photographic chemicals deal with Metol (B.S. 3105:1959) and hydroquinone (B.S. 3103:1959). Copies can be obtained from the British Standards Institute, Sales Branch, 2, Park Street, London, W.1. Price, 4s. each, plus postage.

T. H. James

PHOTOGRAPHIC SCIENCE AND ENGINEERING
Volume 3, Number 4, July-August 1959

A Synchronized Smear Camera for Satellite Surveillance and Detection

JACK T. LEININGER, *U.S. Naval Ordnance Test Station, China Lake, Calif.*

The ballistic fixed-plate camera method of satellite surveillance and detection presents several drawbacks. One is the difficulty of pinpointing the exact time of satellite passage. Another is the inability of the film to record the exposure streak of a faint satellite image. As a result of investigation of other techniques, the synchronized smear camera was developed. Its two main advantages are the long surveillance time capability and the long integrated-exposure possibility. Construction of the camera, mode of employment, and interpretation of the data are described.

With the advent of artificial satellites during the International Geophysical Year, together with the growing conviction in many researchers' minds that there may exist small natural satellites, some method of detecting and recording their presence was sought at the U.S. Naval Ordnance Test Station. Inasmuch as photography seemed a logical means for such detecting and recording, several methods involving the use of cameras were investigated.

In the first method tried, a guided-missile ballistic-type camera was used, employing techniques for determining time and position of the satellite passage very similar to those later recommended by the Society of Photographic Scientists and Engineers for use in the Phototrack Program. In using this method, a fixed-plate camera is oriented so as to have the object of interest pass through the field of view. While the object is in the field of view, a long exposure is made with precisely timed interruptions. This results in a long streak across the plate, with appropriate breaks corresponding to the interruptions made during the exposure. This technique is used at night, and with the star-field background precise trajectories can be determined. For recording exposure interruptions, as required in this technique, a two-channel Brush recorder was used. One channel was used to record the shutter opening and closing, while the other channel was used to record the standard time signals broadcast from WWV, the Central Radio Propagation Laboratory at the National Bureau of Standards, Washington, D.C. With this record, precise shutter-opening-time measurements can be made. This method was workable when it was possible to observe the satellite visually and to position the camera accordingly.

Soon after the launching of the first Russian satellite, however, it became apparent that information about certain pieces of the launching vehicle that were in orbit was unobtainable because the pieces were not large enough to be visible. Thus a need arose for greater surveillance and detection capability for these small pieces, and for very small natural satellites.

One immediately runs into trouble if he tries to use the ballistic fixed-plate camera for surveillance. First, exposure duration on each plate is limited by the build-up of background density. Second, the exact time of passage, if a satellite happens to be recorded, is difficult to pinpoint. And third, and even more serious, the film will not record the exposure streak of a faint satellite image. Because the ballistic camera could not meet all the requirements, other techniques were investigated in search of one that would have good surveillance capabilities for extended periods of time. As a result, the synchronized smear camera for satellite surveillance and detection was developed.

The Camera

The operating principle of this camera is shown in Fig. 1. Its two main advantages are (1) the long surveillance-time capability, and (2) the long integrated exposure that the film receives from the satellite image. In the usual smear technique, the movement of the film behind a narrow slit is synchronized with the image movement to give good imagery of fast moving objects. For satellite work the slit was made large ($5^1/_2$ in.) to gain all that is possible in exposure time for the faint objects with their relatively slow-moving images. If the film were moving at the same rate as the image, the record on the film would appear ideally as a single dot instead of a streak as obtained with the ballistic fixed-plate camera. But because the satellites are not an

Presented at the Annual Conference, Rochester, N.Y., 7 October 1958. Received 12 September 1958; revised 25 May 1959.

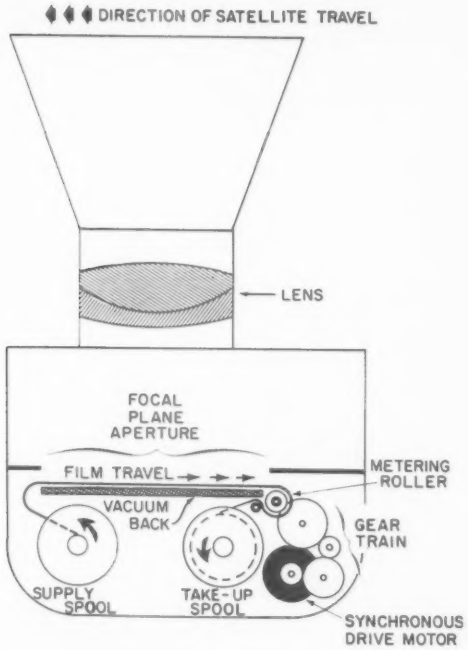

Fig. 1. Diagram of the principles of the synchronized smear camera for satellite surveillance and detection.

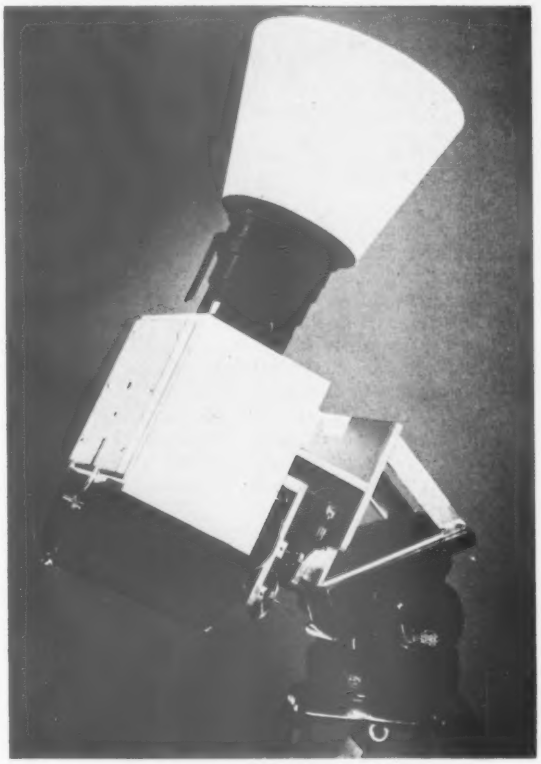

Fig. 2. Basic synchronized smear camera used for field testing the surveillance capabilities of the system.

infinite distance from the camera, the angular velocity changes while the satellite passes through the field of view, and the dot will, in practice, be slightly elongated in the direction of travel.

The prototype camera that was built to field-test the capabilities of this system is shown in Fig. 2. The lens used on this camera has an aperture ratio of $f/3.5$ with a focal length of 10 in. However, any good lens of appropriate focal length with an adequate aperture, good definition, and low distortion, could be used — remembering, of course, that the longer the focal length the faster the satellite image will move across the plate, and the less exposure the film will receive.

A K-24 aerial-camera magazine which holds film $5^1/_2$ in. wide and 54 ft long was modified for use on the prototype camera. The modification was made by replacing the felt-covered pressure plate with a fixed vacuum back, shown in Fig. 3; this permits just enough vacuum to be applied during operation to hold the film flat without impeding film transport at a constant rate. The full 5 by $5^1/_2$-in. open aperture of the magazine is utilized. The film-metering roller in the magazine is driven by a synchronous motor through a gear train which is constructed in a manner similar to the gear train used to drive the lead screw in a thread-cutting lathe. With this type of gear train and a reasonably good selection of gears, almost any film-transport rate desired may be achieved.

It is desirable to be able to match satellite-image

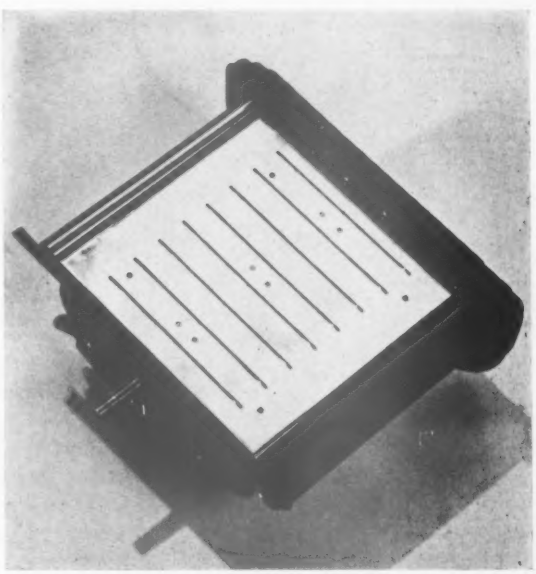

Fig. 3. The vacuum back as installed in the K-24 aerial camera magazine.

angular rates varying from 1° in 30 sec to 1° in 1 sec. At the slowest rate, 1° in 30 sec, an exposure of almost 10 min will be obtained. The 10-in. focal-length lens used in the prototype synchronized smear camera enables a gain of 6,000 times the exposure obtainable with the same lens in a ballistic fixed-plate camera. This increase in exposure would indicate that the synchronized smear camera should record satellites nine magnitudes fainter than can be recorded with the ballistic fixed-plate camera, but because the film motion rate will never be exactly synchronized with the image motion (for reasons explained above) it has been found that satellites only about seven magnitudes fainter can be recorded.

In order that the exact time of satellite passage may be determined, WWV time signals are recorded directly on the film with an NE-2 neon lamp mounted in the camera. Light from the neon lamp passes through an 0.008-in. hole in the lamp-mounting bracket, and exposes the timing marks along one edge of the film. The lamp is placed so as to produce the timing marks on the projected vertical circle. (Vertical circles are great circles which pass through the zenith and nadir and are therefore perpendicular to the horizon. A special case is the observer's meridian, which is the vertical circle that crosses the horizon at the north and south points.) The exact location of the lamp for precise timing of vertical-circle transit of the satellite is obtained by star-calibration methods.

Use of the Camera System

When this system is used for surveillance, a number of cameras are set up to form a fence similar to the telescopes in a Moonwatch fence. There should be a slight overlap of the fields of adjacent cameras so as to completely cover a vertical circle on the celestial sphere from horizon to horizon. If the inclination of the orbit is known, the cameras in the fence projecting the vertical circle should be oriented so as to be perpendicular to the orbit.

The information obtainable from the records produced by this system not only includes the detection of a satellite, but also the time of transit of the vertical circle, the angular velocity of the satellite, and the direction in which it is traveling. The surveillance periods should include those times when it is thought that the satellite might be illuminated by the sun. Surveillance can be carried on during most of the twilight period, as long as the sky illumination is not sufficient to produce excessive background exposure densities. The surveillance period should be extended well into the night because a satellite at a sufficient distance from the earth may be almost continually illuminated, as is the moon.

1959 Annual Conference

26 to 30 October 1959

Edgewater Beach Hotel · Chicago, Illinois

The next National Conference of the Society has been scheduled for October 26 through 30, 1959, at the Edgewater Beach Hotel, Chicago, Ill. Planning for the Conference is well under way.

An extensive papers program is being prepared under the guidance of Charles E. Ives, Papers Chairman, Research Laboratories, Eastman Kodak Company, Rochester 4, N.Y. There will be exhibits of special photographic instruments and equipment. Exhibits Chairman is Arthur E. Neumer, Jr., Hawk-Eye Works, Eastman Kodak Company, 20 Avenue E, Rochester 21, N.Y. Conference Coordinator is Ira R. Kohlman, Colorfax Laboratories Inc., 1160 Bonifant St., Silver Spring, Md.

PHOTOGRAPHIC SCIENCE AND ENGINEERING
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Photographic Image-Density Isolation

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High-contrast photographic prints are made in both positive and negative form and at various exposure levels from a continuous-tone photographic record of a cathode-ray tube radar presentation. A high-contrast positive print and a high-contrast negative print, selected on the basis of exposure received from the original continuous-tone record, are superimposed and printed in register onto a high-contrast material. The resulting image is only part of the original image, that part being equivalent to the selected density range of the original continuous-tone record. The resulting image, having a known relationship to the radar energy displayed on the cathode-ray tube, is extremely useful in studies of radar reflectivity, stability of radar targets, and various other aspects of radar reconnaissance photographic recordings.

A method of increasing the contrast of fine detail by the use of an unsharp masking technique has been described previously (e.g., Yule,[1] Clerc[2]). In the present paper, another masking technique for the isolation of specific density ranges is described. In the discussion which follows all images are sharp.

In radar intelligence studies, it is often desirable to determine the absolute or relative radar reflectivity of certain terrain features, or other factors pertaining to the radar system or terrain. Such radar study may require data showing what targets, or what portion of a target, were presented on a cathode-ray tube (CRT) display within a certain dynamic range; in CRT photography the densities of the photographic image can be correlated to the radiant energy emission of the CRT, which in turn can be correlated to absolute radar reaction. Therefcre, the isolation of a specific density range of a CRT photograph will present an image of a specific radar dynamic range for study or analysis purposes.

Procedure

The isolation of a specific density range (CRT dynamic range) of a continuous-tone CRT photographic record can be accomplished as follows:

The specific density range of a CRT photograph to be isolated is indicated by Step No. 11 in Fig. 1, which is a continuous-tone positive image of a CRT radar display. This positive image is printed twice onto a high-contrast material. One negative (Fig. 2) is exposed so that only those areas of the positive will appear on it which have a density up to but excluding the selected range. The exposure of the second negative (Fig. 3) is longer by just as much as required to print also the areas having the selected density range, but not any with higher density.

Received 19 March 1959.

The second negative (Fig. 3) is printed onto a high-contrast material, resulting in a positive (Fig. 4). This positive and the first negative (Fig. 2) are superimposed and printed in register (Fig. 5) onto a high-contrast material, resulting in an image (Fig. 6) composed of only the selected density range of the original, indicated by Step No. 11.

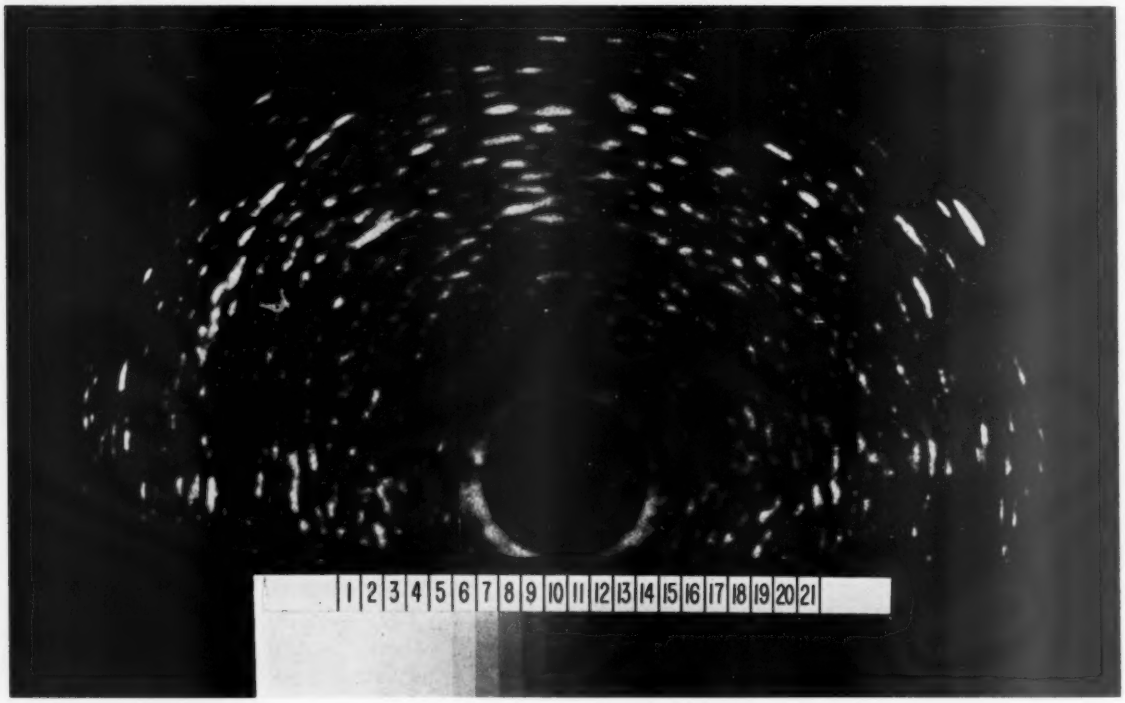
Selection of Image-Density Range to be Isolated

The size of the image-density range to be isolated is determined by sensitometric factors of the high-contrast prints. By suitable selection of exposure and development activity, the image-density range to be isolated can be made of any desired magnitude. For example, a large portion of the whole density range of the photograph in Fig. 1 was treated by this process and divided into separate density isolated images; one such image is that of Fig. 5, the densities isolated having a relatively small range of 1.43 – 1.58; five other such images are shown in Fig. 7. The isolated image-densities of these images are:

Figure 7 Step Number	Density Min. – Max.	Isolated density range
5, 6	0.56 – 0.86	0.30
7, 8, 9	0.86 – 1.27	0.41
10, 11	1.27 – 1.58	0.31
12, 13	1.58 – 1.91	0.33
14, 15	1.91 – 2.16	0.25

If the range of densities selected for isolation is very small, on the order of 0.10 or less, the following additional procedures may be necessary:

1. Process the original continuous-tone photograph to a relatively high gamma, such as 1.5 to 2.0, with the density range of interest placed on the linear part of the film's characteristic curve.



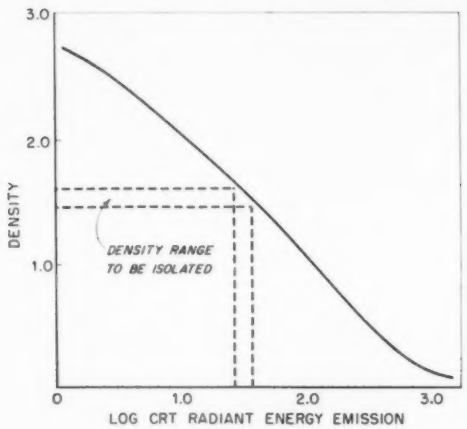


Fig. 1. Original continuous-tone positive image.

2. Print both the high-contrast positive and negative twice before superimposing, to increase the gamma values of these images. This in effect gives a sharper cut-off of those densities which are image-forming and those densities which are not image-forming (the gamma value of a given image equals the product of each printing step, or generation, used to produce the given image).

Required Materials and Equipment

In order to perform this process, especially that part where film registration is involved, dimensionally stable materials and accurately registering equipment should be used. Films with Du Pont's polyester "Cronar" base are suitable; a Kodak registration board or Acme optical/contact printer are suitable for printing.

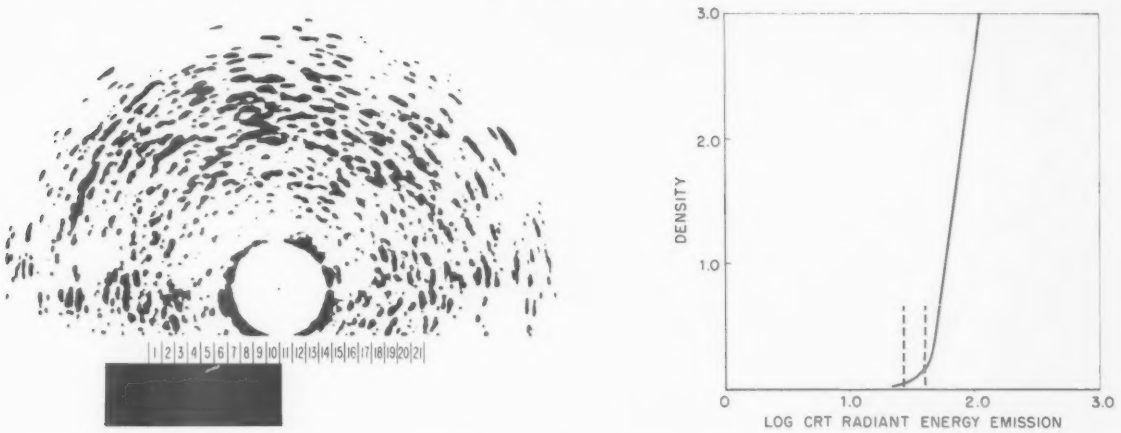


Fig. 2. High-contrast negative "A" image.

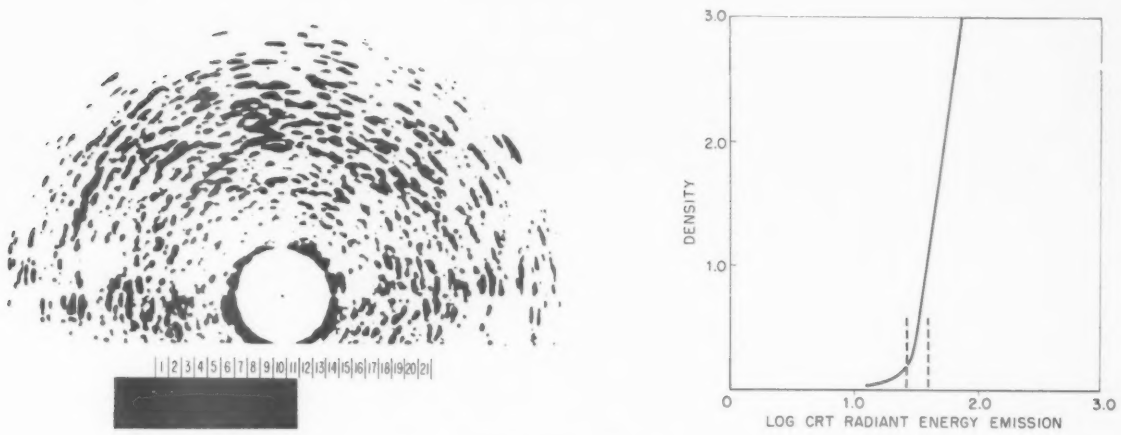


Fig. 3. High-contrast negative "B" image.

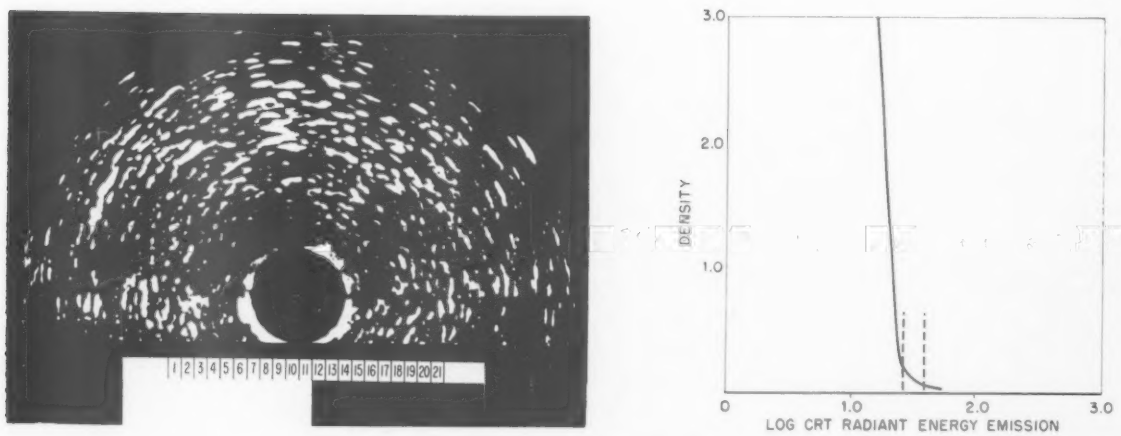


Fig. 4. High-contrast positive "B" image.

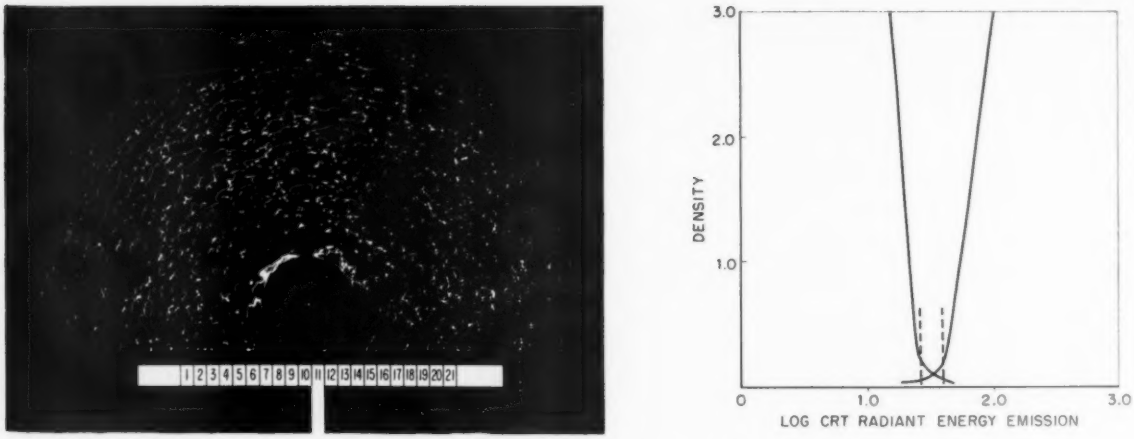


Fig. 5. Negative "A" and positive "B" images superimposed.

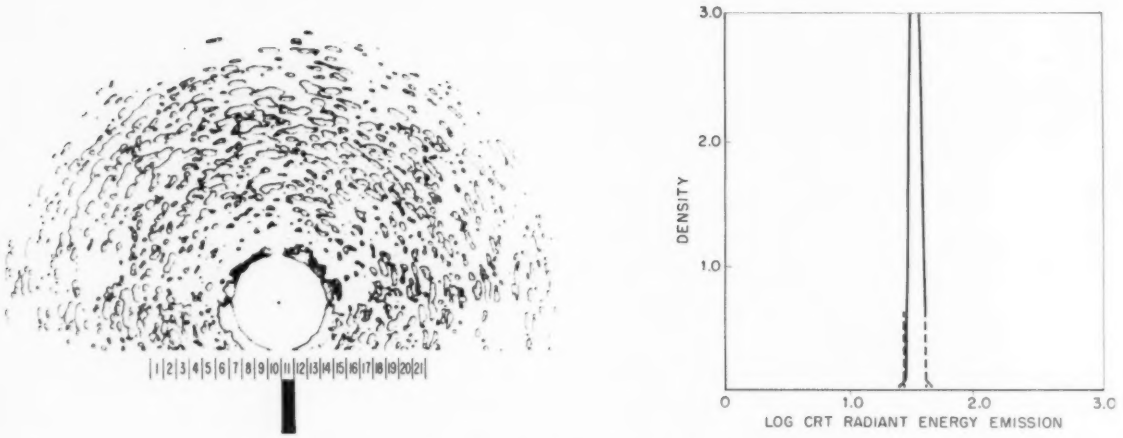


Fig. 6. Print of superimposed negative "A" and positive "B" images showing density isolation.

To be capable of isolating a particular preselected image-density range, sensitometric factors need to be established for each step in the process; and, once determined, should be repeatable by precisely controlling all factors contributing to variation of sensitometric factors.

Conclusion

The process shows its usefulness in the application to radar intelligence studies, since a CRT photograph was used as an example. The process, however, may be found useful in other areas such as aerial photography, industrial and medical radiography, densitometry, etc.

Loss of image quality and resolution is negligible; the process can be performed efficiently, and is extremely accurate in that the densities isolated are none other than those densities indicated by a control density wedge.

By printing the isolated images in register onto a color material, density ranges of a continuous-tone black-and-white record can be presented in terms of color.

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1. Yule, J. A. C., *J. Phot. Soc. Am.*, *11*: 123 (1945).
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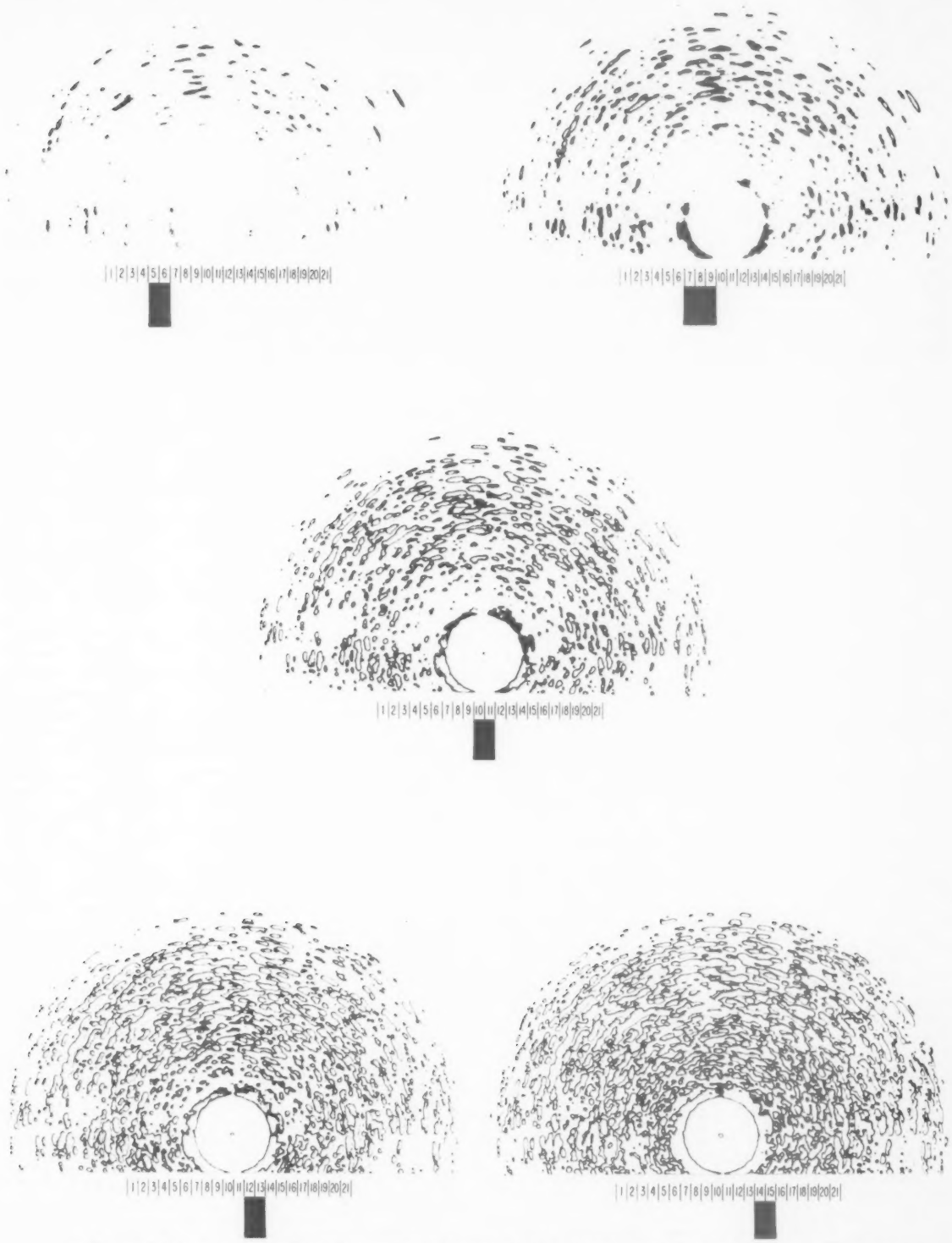

Fig. 7. Isolated density ranges which together comprise a large portion of the density range of the original continuous-tone image.

PHOTOGRAPHIC SCIENCE AND ENGINEERING
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Instrumentation for Cinemicrography

ARTHUR T. BRICE, *Phase Films, Sonoma, Calif.*

The historical development of instrumentation for cinemicrography as a technique of investigation of locomotion at microscopic levels is traced. Prior to 1941, all assemblies for making motion pictures at such levels were custom-built. Phase-contrast development in microscopy has been recognized with a Nobel Prize, and rapid advances in tissue culture technology during the past decade have established a real need for commercially available apparatus in research and education. Functional requirements of instrumentation for cinemicrography are discussed. A flexible system based on commercially available units which would be interchangeable to meet the needs of any specific investigation of locomotion at microscopic levels is outlined.

History of Cinemicrography

The motion picture camera superseded the kymograph and odograph as an instrument of greatest precision for analysis of locomotion in 1888. A photographic emulsion replaced smoked paper and a beam of light took over the functions of transmission mechanisms and stylus. Since that time, many analyses of locomotion under the microscope have been made. Both 16mm and 35mm formats have been used. Exposure frequencies between extremes of one per hour and 1200 per sec have been applied. Various models and modifications of cameras made by André Debrie of Paris have found favor with scientists for use in such investigations. A Debrie was used by Comandon to study the movements of microbes and blood cells prior to 1920. Roger used a Debrie to produce the films of cell division released by the Rockefeller Institute in the late 1920's. Beyer described a Debrie with mirror reflex viewfinder mounted on the shutter in 1951. Weston incorporated a Debrie in his apparatus built the same year. A Debrie was used by this author to produce the educational films of syngamy and alternation of generations in a watermold in 1952. Debries have been in use for bio-assay investigations at the Cancer Research Institute of University of California since 1953.

For analyses requiring high exposure frequencies, Athanasiu used 140 frames/sec for his film on ciliary movement of gills of the clam, published in 1905. Harvey and Loomis began their investigations of the influence of supersonic vibrations on living cells, reported in 1931, with an exposure frequency of 128 frames/sec, but found it inadequate and developed mechanisms capable of 1200 frames/sec.

At the other extreme — analysis of slow locomotion — Chevreton in 1909 reported that Pfeffer had recorded the geotropic movements of plants for 28 days. Instrumentation for continuous photographic recording of movement under the microscope for the same or longer periods of observation — even up to durations of months or years — is by no means out of reach. The rapid development of tissue culture technologies during the past decade has established a real need for it in biologic research and education. The duration of a time-lapse film sequence is limited only by the length of time that a microorganism can be kept alive under the microscope lens. Instrumentation problems are of comparatively simple solution.

Two general types of camera drive have characterized apparatus employed for such analyses. Advantages of continuous drive are that low microscope illumination intensity and longer exposures of film can be used, and that there is reduction to a minimum of the vibration hazard, inherent in all but rotary prism camera designs, resulting from the change-over of mechanical function and load required to start and stop the transport of film. Obviously, the disadvantage of a continuous drive lies in the fact that exposure times required to stop motion and render crisp images of the object can only be controlled by varying shutter apertures. A certain amount of movement of the microorganism may take place when recording at long intervals and correspondingly long exposure times. A minimum resultant lack of image sharpness may be acceptable in bio-assay recordings, but cannot be tolerated if speeds or directions of movement of the organism or any of its anatomical features are to be measured with utmost precision. The disadvantage can be overcome at lapse-time exposure frequencies not greater than about 15 frames/min by synchronizing a commercially available electronic flash-tube microscope illumination system* to fire the recording microsecond flash at midpoint of the shutter opening. Such systems capable of firing a recording flash more frequently than every 3–4 sec are not yet commercially available.

Intermittent drives which turn the camera shaft through a precisely single frame cycle of operation on triggering by clockwork, synchronous motor, or

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* Such as Ascorlight M403 (modified), manufactured by American Speedlight Corp., Middle Village 79, N.Y.

electronic circuit mechanisms have been widely developed and used. Many commercially available industrial repeat cycle timers are adaptable to the programing function. Exposure frequencies and exposure times can be controlled continuously by such means between any limits imposed by the requirements of the problem, the characteristics of the microorganism under investigation, or the purposes of the investigator. Stop-motion motors are standard accessories for all animation process or data-recording cameras.

More detailed descriptions, with complete bibliographic references, of the earlier custom-built installations used for analysis of locomotion under the microscope are to be found in a recent work by A. R. Michaelis, *Research Films in Biology, Anthropology, Psychology, and Medicine*, published by Academic Press, Inc., New York, in 1955.

Starting with Scott's three-phase transformer of the early 1900s, the phase relationships in electrical circuits have been extensively explored and useful applications made of the discoveries. Corresponding developments based on phase relationships in the wave motion of light have lagged behind those in electricity. The discoveries of the 1930s by Zernike were applied first to testing the quality of telescope optical systems and evaluation of defects in concave reflecting mirrors. Armine T. Wilson, who has used the Zernike phase-contrast microscope and cinemicrography to investigate the phagocytosis of streptococci by human blood cells, suggests that it was the need to differentiate living white blood cells that led Zernike to initiate improvement of the microscope. This author can report that Dr. Zernike himself attributes it to the enthusiasm of a botanist when he was shown the chromosomes of an unstained onion root tip in a physics laboratory experiment.

As a result of the experiment, and the botanist's enthusiasm, Zernike disclosed his theories and experimental results to the scientific associates of the optical manufacturing firm of Carl Zeiss, at Jena, Germany, in 1932, and oriented them as to possible applications. A scientific break-through in physical optics was involved -- the production of images of transparent objects based on their effect on the speed of light — and a new means of perception. It was recognized as such by the Nobel Award for Physics to Zernike in 1953.

After the Zeiss firm had acquired his patent rights and developed the phase-contrast microscope, in 1941, a fully integrated assembly of apparatus for production of motion pictures was designed and five units built. These were put into use at research laboratory centers in Germany prior to 1947. Only conventional upright exit-pupil microscopes could be used with these first units. Later a model for inverted microscopes was developed, and described by Michel in 1953. Both units are now commercially available.

The camera is of novel design, featuring ready conversion of film format by means of alternative 16mm or 35mm cassettes and film gates. Low-voltage incandescent, high-pressure mercury vapor, or carbon arc light sources are easily interchanged. The beam splitter for continuous visual observation of the microorganism during filming is equipped with built-in photoelectric light meter. Signal lamps indicate correct functioning of the apparatus and warn of exhaustion of unexposed film in the supply cassette. The camera is synchronous motor driven through a quick-change gear speed selector mechanism providing for 18 exposure frequencies between limits of one per hour and 24 per sec. Exposure time is controlled by a variable aperture rotary sector shutter.

Technical Aspects

The vibration hazard must be dealt with before any technique of cinemicrography can be successfully employed for research or educational purposes. It arises from several different sources. The seismic source should be considered first in designing or planning any installation. Many of the early installations will be found in laboratory basements or cellars reinforced with massive concrete and steel foundations. More recently, the need to mount delicate instruments in airplanes has resulted in development of vibration absorption and elimination systems which are equally effective. The characteristics of absorption pads or mounts of rubber change with the passage of time. Cushions and buffers of knitted-steel wire and precision-formed stainless-steel spring* remain virtually unchanged with the passage of time or exposure to oil, dust, water, etc. The entire apparatus of whatever weight can be isolated from the building by means of such devices and systems. Or, any component of the equipment can be isolated from any other that may be the source of a vibration. Massive weight can be used to damp the frequency and amplitude of vibration from any such secondary source.

Rotary-prism-type cameras present the least vibration hazard. Movement of film is continuous and load on the driving element uniform. In conventional motion picture cameras there is an alternation of mechanical function and load at each single frame cycle of operation. A greater load is imposed on the driving force to pull a frame of film from the magazine and pin it in position. While the film is held still behind the lens, the operation of the shutter requires less force. This alternation of load is an inherent source of vibration in such cameras.

Before a camera is selected for recording microscopic data, it should be carefully tested for static and dynamic balance. Most modern cameras will be found satisfactory if the microscope and camera bases are rigidly joined through a firm support-stand and isolated from any other external source of vibration (Figs. 1, 2, 3, and 4).

Some tissue cell cultures survive and grow well under a microscope in adhesion to the glass of the perfusion chamber or cover-slip preparation. There is a small hazard of the microorganism changing its

* Such as the "Met-L-Flex" systems manufactured by Robinson Aviation, Inc., Teterboro, N.J.

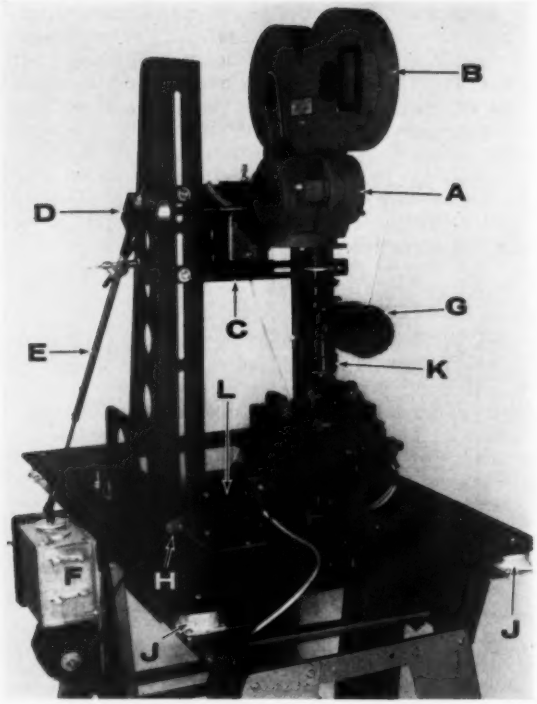

Fig. 1. Support stand and instrumentation assembly for conventional upright exit pupil microscope.
A — Bell & Howell Model 71-KM "Eyemo" 35mm Camera
B — 400-ft film magazine
C — Huber bore-site mount
D — Miter gear box
E — Power transmission shafting
F — Motor and quick-change gear shift speed selector
G — "Miflex" photomicrographic camera modified with beam-splitting prism in place of mirror and wide-angle eyepiece for continuous observation during filming
H — Blackout semaphore balance arm with counterweight
J — "Met-L-Flex" vibration absorptive unit mounts
K — Light trap between optical axes of camera and microscope
L — Blackout semaphore motor box showing side spaced for ventilation

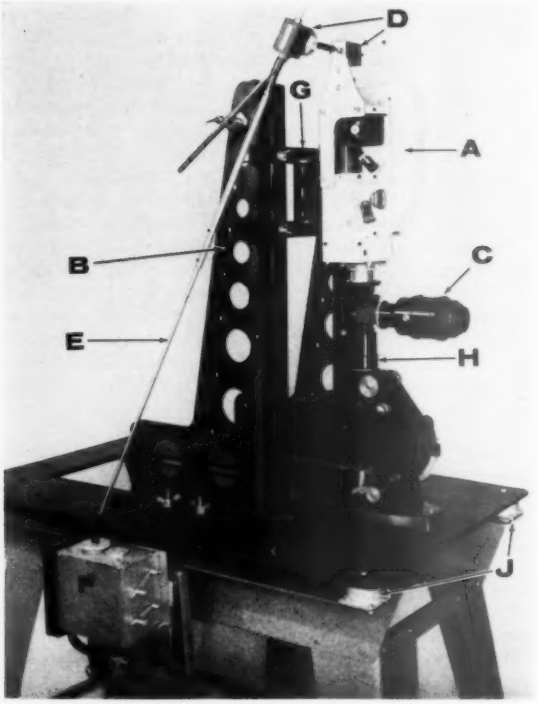

Fig. 2. Support stand and instrumentation assembly for conventional upright exit pupil microscope.
A — "Photo-Sonics" 16mm 1B Rotary Prism Recording Camera, with 200-ft film magazine
B — Left camera bracket
C — "Miflex" photomicrographic camera modified with beam-splitting prism in place of mirror and wide-angle eyepiece for continuous observation during filming
D — Miter gear boxes
E — Power transmission shafting
F — Motor and quick-change gear shift speed selector
G — Huber bore-site camera mount
H — Light trap between optical axes of camera and microscope
J — "Met-L-Flex" vibration absorptive unit mounts

position with respect to the microscope lens or the film as a result of slight tremors of the apparatus. Others, suspended in a liquid medium, may float or sink to the bottom of the chamber. Should they sink to the bottom, unless the preparation is very thin, an inverted microscope may be called for. If perfusion chambers* are filled to the elimination of all air bubbles with the cell culture and its liquid vehicle, there is little risk of movement from vibration within the chamber.

Sound shocks and slight tremors result from the functioning of electromagnetic clutches, solenoids, and switches when the camera is operated at time-lapse exposure frequencies on triggering of stop-motion motors by clockwork or electrical timing and programing devices. The shocks and tremors may be of sufficient vigor to produce movement in the culture chamber. They are also distracting to a micromanipulator who may be performing a very delicate operation on a portion of a single cell. For these reasons, continuous uniform speed drives of the camera, whether of conventional or rotary prism design, are preferable. The power transmission from motor to camera should not include flexible couplings or cable which might be expected to absorb such shock. Torsional deflections of such flexible elements resulting from load variations invalidate the uniformity of exposure frequencies and exposure times

* Such as Model 1292 from the Electro-mechanical Development Co., Houston, Tex., or the "Rose" chamber, distributed by Wahlberg-McCreary, Inc., also of Houston.

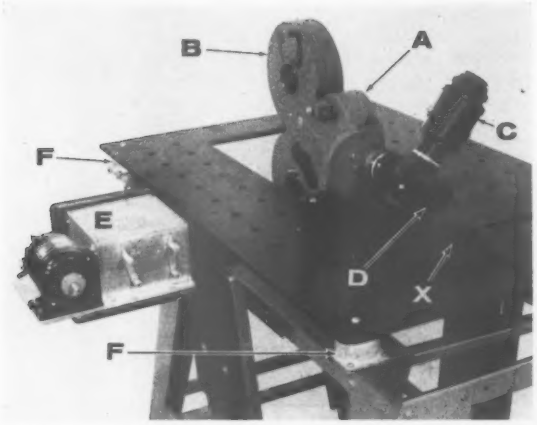

Fig. 3. Support stand and instrumentation assembly for microscope with horizontal exit pupil.
A — Bell & Howell Model 71-KM "Eymo" 35mm Camera
B — 400-ft film magazine
C — "Miflex" photomicrographic camera modified with beam-splitting prism in place of mirror and wide-angle eyepiece for continuous observation during filming
D — Camera element of light trap to microscope exit pupil
E — Motor and quick-change gear shift speed selector
F — "Met-L-Flex" vibration absorptive unit mounts
X — Position of microscope showing slots for bolting micromanipulation or other accessory apparatus in place

essential to the production of film of precision data-recording and photographic qualities.

To be most useful, a support-stand should be adjustable to accommodate microscopes and cameras of different sizes, shapes, and characteristics in suitable relative positions. A microscope of conventional upright design will need the camera above it. For an inverted microscope, the camera must be mounted below. Some microscope designs project the image to the camera in a horizontal direction. Provision must also be made in the design of a support-stand for proper positioning of necessary accessories such as light source, blackout semaphore, micromanipulation apparatus, intervalometer programer, temperature control and recording instruments. The bases of microscope and camera should be rigidly joined and isolated from external sources of vibration by absorption and damping systems.

The illustrations show a number of different assemblies. The so-called "bore-site" mount (Fig. 1, C),* designed for mounting cameras precisely sighted on instrument panels or gun trajectories in airplanes, permits the ready removal and replacement of the camera to exact position, after precise alignment of optical axes of microscope and camera has been established and checked.

The quick-change gear shift speed selector (Fig. 5), driven by a synchronous split-phase, totally enclosed, worm-gear double-reduction, 2 RPM output, 1/150 hp

* Manufactured by Huber Industries, Inc., 4960 Hillside Ave., Cincinnati, Ohio.

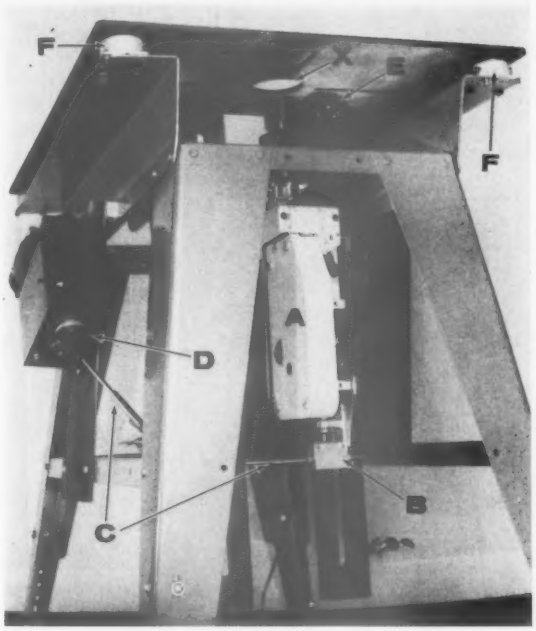

Fig. 4. Support stand and instrumentation assembly for inverted microscope with exit pupil downward.
A — Photo-Sonics 16mm 1B Rotary Prism Recording Camera
B — Miter gear box
C — Power transmission shafting
D — Motor and quick-change gear shift speed selector
E — Wide-angle eyepiece of beam splitter
F — "Met-L-Flex" vibration absorptive unit mounts
X — Aperture for microscope exit pupil

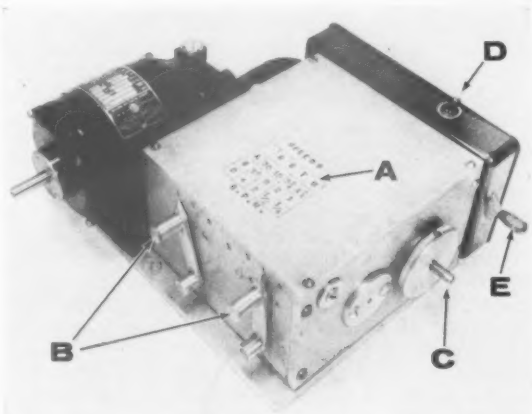

Fig. 5. Continuous drive motor and quick-change gear shift speed selector.
A — Table of gear setting for selection of speeds
B — Gear shift levers
C — Output shaft
D — On-off switch
E — Reversing switch

motor,* provides eleven different speeds for continuous drive of the camera at time-lapse exposure frequencies. For motion analyses at normal cine or higher frequencies, this unit is disconnected and the standard drive motor of the camera is used.

To protect photophobic microorganisms from harmful light intensities during intervals between lapse-time exposures, the light source is blacked out from the microscope by a semaphore arm synchronized with the camera shutter (Fig. 6). The device consists of a small desk-fan-type electric motor which may be stalled for short periods without damage. A cam and microswitch on the camera drive shaft, phased with the camera shutter, closes the electric circuit just before the camera shutter opens. The semaphore arm is lifted out of the light path and held in stalled position by a rubber bumper for the duration of the exposure. When the circuit is broken, it falls again into blackout position of its own weight. This system has been found to be more effective in maintaining uniform film density from frame to frame than direct on-and-off switching of a light source.

Framing the microscope image in the picture space presents more of a problem to the cinemicrographer than to the photomicrographer. The latter need only center the image in the viewfinder. Framing can be done when the negative is enlarged and the print masked or cropped. The cinemicrographer must be able to observe the whole film area and some portion of surrounding areas while filming is in progress. Objects in the microscope image may move into or out of the picture space. He must move the preparation under the microscope lens by means of the mechanical stage to meet the framing requirements of such movements. A number of photomicrographic cameras which reflect a sufficient portion of the microscope field to a viewing screen or eyepiece by means of a swing-out mirror may be modified to provide for such continuous observation and framing. The swing-out mirror may be replaced by a beam-splitting prism of desired transmission/reflection ratio. Most useful in cinemicrography are ratios lying between limits of 75/25 and 90/10. A reticle to outline the film frame area must be added. The use of a wide-angle eyepiece† for viewing the reticle area has been found to constitute a further decided improvement of the unit. Such a beam-splitting device is best fixed firmly to the motion picture camera in the place of its conventional lens rather than to the exit pupil of the microscope. If fixed to the microscope, the added weight may increase the difficulties of maintaining constant correct focus over the long periods of time-lapse sequences. Fixed and adjusted to the camera, it can be removed with the camera when changes of microscope objective or eyepiece are to be made or the rear focal plane of the microscope inspected for adjustment of phase rings. When returned after such changes or adjustments of the microscope, there is no need to re-check alignment of the center of the beam-splitter or its equidistance from film and observation reticle planes.‡

Motion picture cameras designed for technical purposes, such as animation processing or data recording in aviation, missile, and satellite research and development, are considered more suitable for cinemicrography than amateur types. They are in general more solid, steadier, and more thoroughly engineered. Studio and amateur types have built-in features such as sound-deadening, fade-in, fade-out, and panning mechanisms, range and viewfinders, light meters, automatic diaphragms, etc., that are costly and of no particular interest or advantage to the cinemicrographer. The following models have been tested for vibration and shock by mounting over a microscope focused on the tip of a fine thread of glass drawn out in a flame to simulate a micromanipulation tool.

"Acme"§ is an animation process camera available in either 35mm or 16mm format. Time-lapse intervalometers, programing devices, stop-motion drive motors, and clock-face or other auxilliary recording

* Type NSY-12R, manufactured by Bodine Electric Co., 2288 W. Ohio St., Chicago, Ill., and designed by Lindstaedt Laboratories, 109 Fawn Dr., San Anselmo, Calif.

† Such as No. 5160 or No. 50091 from the Edmund Scientific Co., Barrington, N.J., or No. 1020 or No. 1405 from the A. Jaeger Co., Lynbrook, N.Y.

‡ Makes and models of photomicrographic cameras which can be modified and used in this manner are: E. Leitz Co.—"Micro-Ibso"; C. Zeiss Co. — "Milflex"; Bausch & Lomb Co. — Model N; as well as the trinocular elements of American Optical Co. — "Microstar," "Pathostar," and "Phasestar" series of upright exit pupil microscopes.

§ Manufactured by Producers Sales Corp., 2704 W. Olive Ave., Burbank, Calif.

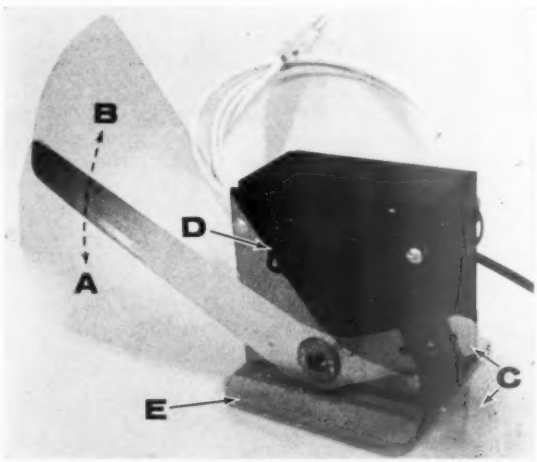

Fig. 6. Double-exposure photograph of blackout semaphore.
A — Blackout position of semaphore in path of light to microscope
B — Semaphore raised position out of light path
C — Semaphore balance arm with lead counterweight
D — Adjustable rubber stopper to limit travel of semaphore
E — Sponge rubber to eliminate noise from semaphore as it strikes the base when it falls

attachments or accessories can be supplied by the manufacturer. Motion analyses requiring exposure frequencies up to 24 frames/sec can be carried out with this unit. The manufacturer has developed a standard modification of the basic instrument to meet the requirement for continuous observation during filming. This consists of a rotating turret in front of the film plane carrying a front-surfaced mirror and three beam-splitters of different transmission/reflection ratios, with viewing eyepiece.

The "Camerette"* is a multipurpose technical data recording system. Immediate interchangeability between 35mm and 16mm formats by change of an aperture plate and film magazine is an outstanding feature. A 45° mirror carried by the camera shutter provides for continuous observation during filming without any loss of illumination intensity at the film such as results from reflection to an eyepiece of part of the beam by a beam-splitter. Accessories integrated to the system include a chronometer to record passage of time on each frame of film, and a small probe-type photoelectric light meter that permits exploration of quarter areas of the film field for illumination intensity and may be calibrated in terms of film speed units. Motion analyses requiring exposure frequencies up to 60 frames/sec can be carried out by this unit. Modifications of the basic system to meet special requirements of cinemicrography proposed by the manufacturer include: elimination of ground glass from the continuous observation viewfinder; coupling for continuous drive of the camera at time-lapse frequencies by slow motor and gear-shift speed selector mechanism, if desired, in preference to intervalometer-controlled stop-motion motor drive, which is standard; modification of intervalometer and stop-motion motor circuits to provide open shutter phasing for comparatively long exposure times; extension tube in place of lens mount for light-lock between camera and microscope.

"Multidata" 35mm and 16mm cameras are also data-recording types.† Integral stop-motion motors are controlled by exclusive electronic features providing for synchronization of exposures by a battery of several cameras. Events occurring in control and test cultures under separate microscopes can be recorded simultaneously be these instruments. An electric output pulse, timed at the precise midpoint of the shutter opening, can be used to trigger an electronic flash tube light source or blackout semaphore or to synchronize any other auxilliary or complementary apparatus. Motion analyses requiring exposure frequencies up to 40 frames/sec can be carried out by means of interchangeable gears. Intervalometer components to meet any desired time-lapse exposure frequency requirements are available. To meet the requirement for comparatively long exposure times in time-lapse cinemicrography, the standaid circuits would be modified to provide open shutter phasing.

"Photo-Sonics - 1B" is a 16mm high-speed rotary-prism-type motion analysis camera.‡ The basic mechanism differs from other high-speed rotary-prism cameras in that the image distortion produced by prism apices is eliminated by a separate adjustable aperture rotary-disk shutter, the movement of which is synchronized with that of the prism, rather than by permanent masks fixed to the apices of the prism itself. This permits a certain amount of control of exposure times whether at time-lapse or high-speed exposure frequencies. Four sets of interchangeable gears provide for exposure frequency rates, controlled within each gear combination bracket by d-c voltage applied, between the limits of 12 and 1000 frames/sec. For time-lapse frequencies, the camera can be driven continuously by the slow motor and gear-shift speed selector. To synchronize blackout semaphore or trigger the electronic flash light source, the manufacturer proposes to provide a cam and microswitch suitably geared to a drive shaft.

* Manufactured by Houston Fearless Corp., 11801 W. Olympic Blvd., Los Angeles, Calif.

† Manufactured by Flight Research, Inc., Richmond, Va.

‡ Manufactured by Photo-Sonics Inc., 2704 W. Olive Ave., Burbank, Calif.

• Book and Journal Reviews

The Green Flash and Other Low Sun Phenomena

D. J. K. O'Connell, S. J., with photographs by C. Treusch, S. J. (Vatican Observatory, 1958). Interscience Publishers, Inc., New York, 1958. 192 pp., 9½ × 6½ in., $6.00.

This book presents a remarkable photographic study of a phenomenon which is sometimes observed in favorable localities at the rising and setting of the sun. The subject is a difficult one for color photography. Color photographs of the green flash have been taken by De Kerolyr and Hanzawa, but color reproductions of these photographs have not been published. The 80 remarkable color reproductions in the present book, selected from the many photographs made at the Vatican Observatory at Castel Gandolfo since June 1954 apparently represent the first to be published in color of the green flash. Most of the photographs were taken at sunset. The flash at sunrise is reported to be particularly difficult to capture on color film, but some beautiful examples of photographs made at sunrise are included. Details are given on the photographic equipment and materials used, and observations on the moon and Venus are included, as well as meteorological notes, experiments on artificial sunsets, examples of scintillation effects, and examples of the effect of incorrect exposure on color rendition. The book also contains many black-and-white reproductions of color photographs, and a brief review is given of earlier observations of the green flash, the theory of the flash, and the factors which influence it. — *T.H.J.*

Inventaire des travaux menés dans le champs de la photographie scientifique au Laboratoire de Physique Générale de l'Université dé Liège [Inventory of works carried out in the field of scientific photography at the Laboratory of General Physics of the University of Liège]

A. Hautot, Etablissements Ceuterick, Louvain, 1958. 380 pp., 6¼ × 9½ in., paper cover.

A program of research on photographic theory, begun at the University of Liège in 1940 and still actively pursued, has resulted in the publication of a large number of papers by Professor Hautot and his colleagues, R. Debot, L. Falla (now professor at the University of Elisabethville) and H. Sauvenier. The program has included work on the distribution of the latent image; various latent image phenomena such as reciprocity law failure, solarization, the Herschel effect, the Debot effect (discovered at the University of Liège), and the Villard effect; chemical sensitization of emulsions; desensitization; and the structure of the developed image. The present book gives an extensive survey of the work of the Liège group. Except for a few paragraphs here and there, it deals only with published work of the period 1940 – 1958, but it serves to bring together in one volume the results of a considerable amount of work published in not always readily accessible journals. — *T.H.J.*

Perspective

Edited by A. Kraszna-Krausz. The Focal Press, 31 Fitzroy Square, London, W.1. Subscription, $7.50 per year.

The first issue of the quarterly review, *Perspective*, recently appeared. The policy of the journal, as set forth in the editorial comment, is "to serve members of the photographic and ancillary industries, the technologists, scientists, business men, and specialist photographers whose job it is to devise or use new tools in new ways and for new ends. They have to progress with progress. . . .Our job is to present them with a total view of what is going on in the photographic industry, how its latest products are used and how the markets respond to them. We shall keep this view world-wide and factual; confined to matters that matter. It will be a multiple view in the sense that it will cover commerce side by side with science and new tools as well as their uses off the beaten track."

Volume 1, Number 1, 1959, contains 112 pages of text and has as feature articles: "What Price Amateur Photography," by Michael Wilsdon; "Focus on Natural History," by M. G. Sawyers; "Not by Silver Alone" (review of non-silver photographic processes), by Martin Hepher; "The Professional's Tool" (including a table in which 25 technical cameras are compared), by L. A. Mannheim; "All the Colour" (comparison of color films and processes), by George Ashton; "Training German Photographers," by Leo Busch; "Pictures on Tape," by W. H. Cheevers; and "Growth of American Photography," by Stephen Blundell. In addition, the issue contains a group of eight "Photographers' Self-Portraits," and devotes 32 pages to short reviews of research papers, new products, methods, and market information.

Activation Energies of Development and Fog Formation

A quarter of a century ago, V. I. Sheberstov[1] defined a "selectivity" factor, U, for developers in terms of the relative rates of image and fog development. U is equal to 100 times the ratio of the time required

to produce a fog density of 0.3 to the time required to produce an image density of 1.5 for a particular exposure level, i.e. $U = 100\,t(\text{fog density } 0.3)/t(\text{image density } 1.5)$. Sheberstov determined U for a number of common developing agents used in the same basic developer formula at temperatures of 15°, 20°, and 25° C. The value of U depended upon the developing agent, and generally was less the higher the temperature for a particular agent.

In a recent series of papers,[2–5] Sheberstov and his associates have determined overall activation energies for image development, E_i, and fog formation, E_f, under various conditions. By use of the Arrhenius equation, they related the selectivity factor at a particular temperature to the difference in activation energies, $\Delta E = E_f - E_i$, and obtained the equation: $\ln U = \ln k_1 + k_2 \Delta E$. The calculated activation energies are based on measured rates of density formation at two temperatures. Possible changes in density-silver relation and in pH with change in temperature are not considered.

The activation energy for the reduction of silver halides by stannite ion, which does not discriminate between exposed and unexposed areas of the film and hence does not develop an image, is very small[2,5] and may be nearly zero. The measured temperature coefficient of the reaction is about 1.5, which is about that expected if the rate is controlled by diffusion.

Metol-hydroquinone and Metol developers containing 25 grams sodium sulfite per liter were used in investigations of the effects on E_f and E_i of the duration of the second ripening in the preparation of the emulsion (chemical sensitizing stage) and of antifoggants added to the emulsion or to the developer.

As the time of second ripening increased, E_f decreased continuously, whereas E_i decreased to a minimum which coincided with the time of optimum ripening and subsequently remained constant or increased slightly.[3,5] The difference ΔE increased to a maximum and then decreased. In one example, samples of an emulsion with 2 mol % iodide were ripened at pBr 3.2 for 15 min, 1 hr, 2.5 hr, and 4 hr. The corresponding E_f values were 36, 32, 28, and 20 kcal/mol, respectively: the E_i values were 28, 14, 15, and 14 kcal/mol; and the ΔE values were 8, 18, 13, and 6 kcal/mol. The maximum light sensitivity was reached after 1.5 hr. In this, as in other emulsions of the series, U increased with increasing ΔE.

The activation energies of both fog formation and image development increased with increasing iodide content[3,5] in a series of bromide emulsions containing 0, 2, and 6 mol % iodide. (Sugai and Furuichi[6] also had observed an increase in activation energy of image development by a Metol solution as the iodide content of the emulsion increased over the range 0 – 40 mol %). The activation energies decreased with increasing chloride content in a series of emulsions containing 0, 15, and 30 mol % chloride. ΔE likewise decreased with increasing chloride content. E_f values for the 0, 15, and 30 mol % chloride were 31, 26, and 23 kcal/mol; E_i 14, 12, 11; ΔE 17, 14, 12.

In the investigation of the effect of antifoggants,[4,5] a silver iodobromide emulsion with 2 mol % iodide was prepared and, shortly before the maximum sensitivity was reached in the second ripening stage, benzotriazole was added (1.3×10^{-6} moles per gram gelatin) and ripening was continued. In comparison with the control, the benzotriazole had little or no effect on E_i but increased E_f and hence ΔE. As an example, values of E_f, E_i, and ΔE for a control emulsion after 4-hr second ripening were 24, 14, and 10 kcal/mol, respectively, whereas those for the emulsion which contained the benzotriazole were 29, 15, and 14 kcal/mol. Excess bromide in the emulsion also tended to increase E_f and ΔE. Addition of bromide to the developer (1 and 2 g KBr/l) increased E_f and had less or no effect on E_i. Hence, ΔE increased. Benzotriazole (0.5 and 0.2 grams/liter) added to the developer also increased E_f and produced less or no increase in E_i. The authors conclude that the effect of any antifoggant which increases selectivity is due to the increase in ΔE.

In all of the preceding work with developers and experimental emulsions, ΔE was positive. This agrees with results reported by other investigators.[7,8] However, values of E_f which were less than E_i were sometimes obtained with factory-made emulsions used with developers which contained little or no antifoggant.[4] In such cases, U increased with increasing temperature. The authors state that "the explanation of factors belonging both to the emulsion layer and the developer leading to negative values of ΔE is of definite interest but remains beyond the limits of this paper."

Sharlandzhiev and Chel'tsov[9] have reported results of an investigation of the temperature dependence of color development by several derivatives of *p*-phenylenediamine used in a solution which contained 0.01 *M* developing agent, 2 grams sodium sulfite, 1.2 grams hydroxylamine sulfate, 75 grams potassium carbonate, and 2.5 grams potassium bromide per liter. The rates of development followed the Arrhenius equation (range 10° – 25° C). The overall activation energies calculated for both silver formation and dye formation depended upon the coupler used. Thus, values obtained for silver development by N,N-diethyl-*p*-phenylenediamine in the presence of magenta, cyan, and yellow dye-forming couplers were 20, 23, and 24 kcal/mol, respectively, and for dye formation 16, 21, and 34 kcal/mol. The authors suggest that the reactivity of a coupler can be characterized by the value of the activation energy. — *T.H.J.*

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Résumés by T. H. J.

Recent Developments in Photographic Sensitivity

Eiichi Mizuki, pp. 101–114

This paper reviews experimental and theoretical work published during the past five years on the physical and photochemical properties of silver halide crystals, and the sensitivity of silver halide-gelatin emulsions. The paper cites 215 literature references.

Dichroism of Pyrazolone Dyes in Stretched Poly(vinyl alcohol) Sheets

Hisatake Ono, Yoshie Tanizaki, and Ikuzo Tanaka, pp. 115–120

Pyrazolone azomethine dyes have two absorption maxima in the visible region, and these maxima can be displaced by changing the nature of the radicals substituted on the 3-carbon and 1-nitrogen atoms. From a study of the absorption spectra of a number of such dyes dissolved in solvents covering a range of dielectric constants, Brown, Graham, Vittum, and Weissberger (*J. Am. Chem. Soc.*, *73:* 919 (1951)) concluded that the two bands were *x*- (long wave) and *y*- (short wave) bands in the sense of Lewis and Calvin. They attributed the *x*-band to excitation involving large contributions from resonance structures in which the pyrazolone 2-nitrogen atom is negatively charged, and the *y*-band to excitation involving structures in which the negative charge is carried largely by the carbonyl-oxygen atom. Dr. Ono and his associates questioned this interpretation. They sought experimental evidence for the origin of the two bands in measurements made with polarized light of the absorption spectra of stretched sheets of poly(vinyl alcohol) dyed by two water-soluble dyes: 4-[*p*-(dimethylamino)phenylimino]-3-methyl-1-(*p*-potassium sulfophenyl)-5-pyrazolone and 4 [-p-(dimethylamino)benzylidine]-3-methyl-1-(*p*-potassium sulfophenyl)-5-pyrazolone. The poly(vinyl alcohol) had a mean degree of polymerization of 1500 and was used in layers 0.2 mm thick. These were soaked in the dye solutions. After drying, the sheets were stretched at 70°–80° C. The dichroic spectra were measured for both dyes and are illustrated by graphs. An analysis of the absorption spectra indicates that the two absorption bands do arise from two absorption systems, and that the system responsible for the long wave absorption is the one which is oriented in the direction of elongation in the stretched film. By comparison with models drawn to scale, using van der Waals radii given by Pauling, it is concluded that the long wave band is associated with the chain connecting the dialkylamino nitrogen and the carbonyl oxygen, whereas the short wave band is associated with that connecting the dialkylamino nitrogen and the 2-nitrogen of the pyrazolone ring. This is just the opposite of the conclusions reached by Brown *et al*. The present explanation of the origin of the bands will account for the displacement of the absorption maxima caused by changes in the radicals substituted in the 1 and 3 positions on the heterocyclic ring.

Characteristics of Photographic Materials Sensitive to Electrons (V). Physical Properties of Developed Images

Mataichi Tajima, pp. 121–128. Cf. *PS & E*, 3: 41 (1959).

Measurements of graininess, granularity, resolving power, turbidity, and sharpness were made on three photographic materials used in the electron microscope. Fuji Process and Kanto KSK No. 2 and No. 3 plates were exposed to electron beams, x-rays, and light, and were developed in various solutions.

Graininess was determined in terms of the enlargement needed to produce an apparent graininess equal to the standard. The graininess of all materials for all developers tested was negligible for enlargements to 7.5 times. With Fuji Process plates exposed to 50 kv electrons, equal graininess was obtained at enlargements of 15, 12.5, and 10 times for development in DK-20, D-72 (1 :2), and D-11, respectively. Similar results were obtained with the other plates. Measurements of the Callier coefficient indicate that the developed grains are larger on plates exposed to electrons than to light. Granularity measurements made in terms of the standard deviation of density from the mean, determined from microphotometer traces, showed larger granularity in images produced by electron and x-ray exposure than by light exposure. The standard deviations measured with a scanning area of 100 sq μ on Fuji Process plates developed to a density of 0.49 in D-72 (1:1) (4 min at 20° C) were 1.30 for 1 sec light exposure, 1.70 for electrons, 1.75 for 70 kv x-rays, and 1.60 for 130 kv x-rays. The minimum resolvable separation for Fuji Process plates exposed to light was 8.8 grain diameters, whereas it was 11 to 14 for exposure to electrons (grain diameter about 0.57 μ). A curve showing the size-frequency distribution of grains in the Fuji Process plate is given, and the optimum density ranges for sharpness, resolving power, and graininess are listed.

Dr. Tajima concludes that electron exposures produce images of higher graininess than light exposures. Differences in graininess between two materials are smaller for exposures to electrons than to light. Developers such as Microfine and DK-20 are effective in reducing graininess for electron exposures, but they reduce sharpness. Certain organic antifoggants are effective in reducing graininess. Electron exposures give poorer results than light with respect to both turbidity and resolving power.

Rapid Analysis of Silver in Waste Fixer by Colorimetry

Katsuhiro Iino, pp. 129–132

A method for the rapid determination of silver in waste fixing baths, such as result from motion picture processing, has been investigated. The method depends upon the following steps: (1) Silver ions in

the bath are converted to silver sulfide by addition of sodium sulfide in buffered solution; (2) The absorption of radiation of wavelength 372 mμ by the silver sulfide is measured with a photometer; (3) The amount of silver sulfide is determined by reference to a standard curve relating optical density to the amount of silver. The standard curve is obtained by making measurements on solutions of known silver content. The reagents used are based on Kieser's colorimetric method (*Phot. Ind.*, 35: 948 (1937)) except that the pH is adjusted to 9.8 – 11 with sodium hydroxide to avoid turbidity from aluminum hydroxide. The method requires only about one quarter of the time needed for chemical methods and the error is only 2.1 – 4.5%.

Studies of Simultaneous Development and Fixing of Multilayer Color Films

HIDESABURO GENDA AND SOUICHI KUBO, pp. 133–137

Monobath processing has been successfully used in the past for black-and-white film. The application of the monobath idea to the processing of color film is more difficult, because the different rates of development and fixation in the different layers of the color film makes it difficult to balance the color. The authors made a systematic investigation on a monobath of the effects of varying the concentrations of diethyl-*p*-phenylenediamine (4–8 grams/liter), hypo (10 – 100 grams/liter), and sodium hydroxide (12 – 36 grams/liter) on the fog formation and image development in each of the three layers of color emulsions. Curves are plotted for fog in each layer as a function of concentration of each of the three variables for Oriental Color paper, and characteristic curves are given for each layer and each concentration. Data also are plotted for Eastman Color Positive film for different concentrations of developing agent. On the basis of these results, a formula for a combined developer-fixer was worked out. To test the possibility of also combining a silver bleach in the same solution, tests were made on the rate of bleaching of silver in a ferric-ethylenediaminetetraacetate solution as a function of pH, and rate data are plotted. The authors conclude that a single solution for development, fixation, and bleach is possible and suggest a formula for use with Eastman Color Positive film in which the ferric ion complex formed by a mixture of ferric ammonium citrate and tetrasodium ethylenediaminetetraacetate acts as the silver bleach.

Photographic Properties of Silver Molybdate Emulsions

YOSHITADA TOMODA AND MASAMI KAWASAKI, pp. 138–142

Silver molybdate emulsions were prepared by a neutral process and the light sensitivity, gamma-ray sensitivity, and suitable conditions for development were studied. In the preparation, silver nitrate (3 grams/25 cc) and sodium molybdate ($Na_2MoO_4 \cdot 2H_2O$ 3 grams/25 cc) solutions were added simultaneously to a gelatin solution (3 grams/25 cc) in 6 min at 50° C. The emulsion was coated on glass plates without ripening, refrigerated until set, and bathed in water to remove soluble salts. It was then soaked in alcohol and dried immediately. The drying should be effected in 1 – 2 hr to avoid fog. Suitable developers are: chlorohydroquinone, 3 grams, and sodium sulfite, 2 grams, in solution (presumably 1 liter) at pH 7.58; Metol, 2.5 grams, with acetic acid in solution at pH 4.13; chlorohydroquinone, 3 grams, Metol, 0.3 grams, and sodium sulfite, 2 grams in solution at pH 7.6; *p*-hydroxyphenylglycine, 3 grams, and sodium carbonate, 2 grams, in solution at pH 8.69; and pyrogallol, 5 grams, and sodium sulfite, 2 grams, in solution at pH 7.70; all used at 18° C.

The sensitivity of the emulsion depended markedly on the gelatin used. Characteristic curves are given for eight gelatins. The sensitivity was especially low in emulsions prepared with inert gelatins. Citric and tartaric acids added in the gelatin solution increased the sensitivity, whereas oxalic and acetic acid decreased sensitivity. The silver molybdate emulsion is sensitive to ultraviolet radiation and to visible light up to 4529 A. The emulsion also is sensitive to x-rays and gamma-rays, but the sensitivity is very low.

When sodium tungstate was added in amounts up to 2 mol % to the molybdate solution, the sensitivity of the emulsion was lower than that of the pure silver molybdate. At higher tungstate content, the sensitivity was greater than that of the pure molybdate, and increased with increasing tungstate content (up to 50 mol %, the maximum reported). Since the solubility of the mixed tungstate-molybdate is higher than that of the pure molybdate, a developer of lower potential should be used. Characteristic curves of the pure molybdate, 20 mol % tungstate, and 50 mol % tungstate emulsions exposed to light and to gamma radiation and developed in the chlorohydroquinone-Metol developer are compared with the corresponding curves obtained with gaslight paper similarly exposed and developed in D-72 (1:1). The sensitivity of the gaslight paper is of the order of 100 times that of even the 50 mol % molybdate-tungstate emulsion for both types of exposures. A special use of the molybdate emulsions is suggested for dosimetry of high intensity gamma radiation.

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Résumés by S. C. Goddard

Use of Polymers in Photography. I. Polymeric Films as Bases for Light Sensitive Materials

P. V. KOZLOV, pp. 3–11

The replacement of cellulose nitrate by triacetate as a film base is described, and the properties of the newest types of base — polyethylene terephthalate and polycarbonates — are discussed.

Slow-Motion Cinematography with Multiple Reflection

A. S. Dubovik, P. V. Kevlishvili, and G. L. Shnirman, pp. 12–19

An optical system for very high-speed cinematography achieves a rapid displacement of the image by multiple reflection of the light beam in the wedge-shaped gap formed by plane mirror surfaces cut in two cones mounted with parallel axes and rotating in opposite directions. A camera (LV-1) using this system has been built for the photography of detonations and similar phenomena, and was shown at the Brussels Exhibition. Ten reflections are obtained between the two rotating mirrors, and after reflection the moving beam passes through a series of lenses which image it on a moving band of film. In this way taking frequencies of 33.33 million frames/sec are reached. An electronic system has been devised to ensure exact synchronization of the initiation of the phenomenon to be studied with the proper stage in the working of the mirror system.

Nonlinear Color Separation Characteristics

L. F. Artyushin and N. F. Semenova, pp. 20–31

If a linear formula does not allow the necessary accuracy in calculating the effective densities over the whole range of concentrations per unit area of dyes being copied, a more accurate quadratic formula can be constructed from the results of extended color separation trials. It is suggested that the coefficients in the formula be called the color separation characteristics of the light sensitive system. The numerical values of these coefficients are determined by the method suggested by way of the individual effective densities and the nonlinear deviations. The nonlinear color separation characteristics of the red sensitive layer of DS-2 negative film have been determined from concrete experimental data, and used to derive a quadratic formula for the calculation of the effective densities of the positive dyes. It is shown that if additivity of the effective densities does not hold, the error in the calculation by the linear formula may reach ±0.2 in individual cases, while errors in calculation by the quadratic formula do not exceed ±0.06 on the average. (*Translation of authors' abstract*)

Theory of the Development of the Latent Electrophotographic Image

I. V. Anfilov and V. M. Fridkin, pp. 32–34

A mathematical analysis is made of the kinetics of development of an electrophotographic image, consisting of a charge on the surface of a dielectric, by a colloidal solution, or suspension of a dye. A differential equation is set up for the motion of a particle through the liquid under the influence of the potential field of the image, and from this the time required for complete development is derived by consideration of the final state when a sufficient number of charged particles has been withdrawn from the solution to neutralize the surface charge.

Theoretical Basis of the Dependence of Latent Image Regression on the Energy of Weakly Ionizing Particles Acting on a Photographic Emulsion

K. S. Bogomolov and K. M. Romanovskaya, pp. 35–37

Earlier experimental results on the regression of π^--meson tracks have shown that the degree of regression decreases with increasing ionization, although the dependence is weak. The fluctuation theory of Bogomolov is invoked to explain this phenomenon. According to the theory, the factor chiefly affecting the developability of a grain is not the energy absorbed by the grain but the number of primary ionizations which are produced in it by a charged particle. Larger development centers, formed by a larger number of primary ionizations, regress more slowly than the smaller centers. On the basis of a Poisson distribution of the primary ionizations, a mathematical analysis is made to give an expression for the degree of regression which is in good agreement with the experimental data.

Photographic Activity of Gelatin. I. A Physico-Chemica Method of Analysis of the Active Constituents of Gelatin

A. L. Karpova, pp. 38–48

Photographic gelatins were studied by heating their aqueous solutions with silver nitrate for 24 hr at 80° C, and then adding potassium iodide and back-titrating. Several such determinations were made with each gelatin, the silver nitrate concentration being varied over a wide range. Curves of the combined silver plotted against silver nitrate concentration showed a stepped structure. The steps and plateaus are interpreted as due to combination of the silver ions with complexing, sulfiding, and reducing components, and the amounts of each are deduced. The method is time-consuming, and another method was worked out in which the full quantity of silver nitrate was added to the gelatin and, after the end of the reaction, the reaction mixture was divided into three portions. To one was added potassium dichromate, which oxidizes both free silver and silver sulfide; to another, potassium persulfate, which oxidizes free silver only: the third received no oxidizing treatment. All three were titrated as in the earlier method after the excess of oxidizing agent had been destroyed with sodium sulfite. From the titration figures, the content of complexing, sulfiding, and reducing components were calculated. Results were in good agreement with values obtained from the stepped curves.

Two types of complexing component are recognized, one which accelerates and one which retards digestion. The rate of digestion depended linearly on the concentration of the former and inversely on the concentration of the latter. It does not appear to depend on the quantity of center-forming components present. A method of calculating the proportions of a blend of two gelatins to give a desired ratio of accelerators and retarders is described. Some criticism of an earlier paper by Zimkin and Yafarova (*Zhur.*

Nauch. i Priklad. Foto. i Kinemat., 2:340 (1957)) is appended.

Influence of Iodide on the Properties of an Ultra-Fine-Grain Nuclear Emulsion

N. R. Novikova, pp. 49–55

The composition of a standard nonsensitized, ultra-fine-grain emulsion was varied by the addition of different quantities of potassium iodide during making. Dispersity, light sensitivity, electron sensitivity, and α-particle sensitivity were studied as functions of iodide content. The effect of iodide on α-particle sensitivity is similar to its effect on light sensitivity; speed rises to a maximum and then falls as the silver iodide content rises. The effect on electron sensitivity is different; the speed is always less when iodide is added. When gold sensitization is used, the degree of sensitization falls off as the iodide content is increased. In this type of emulsion, made with a high concentration of excess silver, the degree of dispersity increases to a maximum as the iodide content is increased, after which it falls again.

Simplified Photogrammetry without Special Cameras

N. M. Zyuskin, pp. 56–60

For many purposes photogrammetric measurements must be made on photographs which have not been taken with special photogrammetric cameras. One method of making such measurements uses a marked sheet on which the print is pasted, the markings being set out according to the focal length of the camera. In a second method a measured square card with a circle inscribed in it is placed on the ground in the picture area, and a perspective grid is constructed from its image in the photograph. Finally, perspective constructions are described for the measurement of photographs taken with an unknown camera, provided that straight lines are present in the picture which are parallel in nature.

Reciprocity Failure in Silver Bromide Crystals

V. V. Gladkovskii, pp. 61–62

When a large crystal of silver bromide is exposed to light, silver atoms are formed by the capture of photoelectrons by silver ions at the surface, causing a fall in the dark conductivity. Measurement of the dark conductivity after exposure shows a reduction followed by a re-establishment of the original conductivity. The results indicate that the latent image in large crystals differs from that in emulsions in that thermal decomposition after exposure is not confined to single atoms of silver but extends to larger groups.

The Limiting Gradient of the Isodensity Curve (Reciprocity Failure Curve for a Given Density) of a Photographic Layer

P. V. Meĭklyar, pp. 62–64

In an earlier paper (*Zhur. Eksperim. i Teor. Fiz.*, 23: 217 (1952)), the author, on the assumption that a latent image center with two or more silver atoms is stable, deduced that the limiting slope of the d log It vs. d log t curve should approach 0.5 as the exposure time is increased to infinity. In the majority of experiments cited this was borne out. A mathematical analysis of the situation gives an explanation of the limiting value of 0.5 and the method is extended to show that when three atoms are necessary for stability the limiting slope is 2/3. In general, when one more than m atoms are necessary for stability, the limiting slope is $m/(m + 1)$.

Fluorescence of Dyes Adsorbed on Certain Semi-Conductors

I. A. Akimov, pp. 64–66

The fluorescence of a number of dyes adsorbed on semi-conductors has been studied at temperatures of 20° and −18° C. The dyes were fluorescein, eosin, erythrosin, rhodamine B extra, methylene blue, chlorophyll, magnesium phthalocyanine, 3,3′-diethylthiatricarbocyanine iodide, 3,3′,9-triethyl-4,5,4′,5′-dibenzothiacarbocyanine bromide, and 3,3′-diethyl-5,5′-dinitrothiacarbocyanine *p*-toluenesulfonate. The adsorbents were silver halides, thallium halides, and certain metal oxides. None of the dyes fluoresced when adsorbed on zinc oxide, lead monoxide, thallium halides, or silver halides, but all fluoresced when adsorbed on magnesium oxide, barium oxide, paper, cotton, or gelatin. A sensitized fluorescence of the semi-conductors, when irradiated with exciting radiation for the adsorbed dyes, was not observed. Studies carried out by other workers with photographic emulsions are considered to be of doubtful significance because of the fluorescence produced by dyes adsorbed onto the gelatin.

Tekhnika Kino i Televideniya

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Résumés by S. C. Goddard

Modern Black-and-White Cine Negatives and a New Slow-Working Developer

S. M. Antonov, pp. 41–7

Comparison of figures obtained in 1957 with those obtained in 1935–1937 shows that the modern processing of black-and-white cine-negative film in the USSR is now more uniform, the amount of developed silver in the film is lower and does not exceed 0.02 gram per running meter, while the developed density and contrast are lower on the average. The newer cine-negative films have a characteristic curve with a very short straight-line portion, and with a pronounced upward convexity. Such films are developed in the majority of cases, to a maximum density of 1.1 — 1.5, rarely exceeding 1.7, and a density range of 0.9 — 1.2. Work carried on in the Mosfilm studios has shown that a gamma of 0.55 ± 0.05 should be aimed at, and a slow-working developer has been evolved to allow this to be obtained easily and constantly under production conditions. The formula is: Metol 1.5 grams, hydroquinone 1.0 grams, sodium

sulfite (anhydr.) 100 grams, borax 1.5 grams, boric acid 2.0 grams, potassium bromide 0.15 grams, water to 1 liter. The working pH is 8.6 and the temperature of development 18°C. The time of development varies from 10 to 13 min, according to the characteristics of the film. The anhydrous sulfite must not contain more than 0.6% sodium carbonate. Processing-laboratory tests of the developer with a suitable addition of a replenisher of the same composition as the developer, but without the bromide, showed that the desired constancy of sensitometric properties can be maintained.

New Methods and Apparatus for Testing Cine Cameras

O. I. Reznikov, pp. 62–5

The apparatus described is an autocollimator into which are inserted, in turn, three transparent test objects, with appropriate illumination. The camera is aligned and exposures are made. The first test object is intended to determine frame stability, the second to test the accuracy of setting of the distance scales on the objectives, and the third to check the correspondence between the framing of the viewer and the framing on the film. The over-all length of the apparatus does not exceed 600 mm and the test objects are 220 by 160 mm in size. A design for a general-purpose autocollimator is given.

Tekhnika Kino i Televideniya

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Résumés by S. C. Goddard

A Double-Plate Crystal Light Modulator

G. S. Arushanov, pp. 32–38

The crystal light modulator, making use of the change in birefringence of a $(NH_4)H_2PO_4$ crystal in a varying electric field, has been under study for some time in the NIKFI laboratories as a device for recording sound on film. The two-plate, three-electrode form, which gives a greater dynamic range than the single-plate form, is analyzed theoretically. The best working conditions, the value of the polarizing voltage, and the harmonic distortion arising under these conditions are discussed.

A Study of the Dynamics of Two-Position Temperature Control of Developer Solutions

M. B. Khalameĭzer, pp. 46–53

In a two-position temperature control system, the heat input can have only two values, an upper and a lower, ranged on either side of the required temperature. The performance of such a system is analyzed mathematically by the method of "harmonic balance," based on the phase-amplitude characteristic of the equipment under control and the amplitude characteristic of the lumped nonlinear elements of the regulator, the linear part of the circuit acting as a low-frequency pass filter. The total effect is to convert the square waveform of the heat-input temperature curve into a sine wave. The system of calculation allows a preliminary determination to be made of the frequency and amplitude of the self-oscillation of the system, the calculation being more exact, the greater the low-frequency filtering action of the system. The calculation is claimed to be simple, to give good agreement with experiment, and to be suited to engineering requirements.

Influence of Halation on the Resolving Power of Photographic Films

I. A. Novikov, p. 61

Experiments in which the thickness of the antihalation layer was varied from 0 to 10 μ failed to detect any difference in the resolving power of the samples. The results hold both for the case in which the emulsion is coated on top of the antihalation layer, and for that in which the emulsion is coated on the opposite side of the base. The explanation suggested is that, under the conditions of resolving power measurement, the image of the test object is formed at the surface of the emulsion and little part is played by reflected light.

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Résumés by S. C. Goddard

"Duping" of Color Film with External Masking

L. F. Artushin, T. N. Baikalova, N. S. Ovechkis, and N. F. Semenova, pp. 7–16

In the system described for duplicating color motion picture films, masks are prepared by exposing the color negative through color-masking filters onto black-and-white film, which is then developed to a fairly low contrast. The color negative is then combined with each negative in turn in a special printer, and printed on black-and-white stock through the appropriate printing filters to give masked color-separation positives. These positives are printed through selective filters onto multilayer color film to give the dupe negative, from which positives are prepared as from the original negative. The choice of filters for the different stages, the sensitometric characteristics of the process, the choice of the black-and-white materials, and their processing and printing conditions are discussed in detail.

Motion Picture Projection with Xenon Discharge Lamps

G. L. Irskiĭ, pp. 29–44

Detailed information is given on the performance of two Soviet-produced high-pressure xenon discharge lamps for motion picture projection, one for alternating current and one for direct current. A comparison is made with other light sources used in cinematography. Four Soviet projectors are now fitted with the xenon lamps — one 16 mm and three 35 mm. One of the latter is roughly twice as powerful as the B.T.H. model. At the present state of Soviet light-

ing technology, it will be possible to fit out all small and medium sized theaters with projectors with xenon lamps, and more powerful sources are envisaged which will make it possible to use the same type of lighting in the largest theaters.

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Résumés by S. C. Goddard

High-Speed Line Camera with Mirror Scanning

S. M. Provornov and O. F. Grebennikov, pp. 46–51

A mathematical analysis is made of a number of rotating-mirror systems used for image displacement in high-speed cameras. It is shown that from the point of view of the speed of image displacement, it does not matter whether the intermediate lens comes before or after the mirror system; but the rotation of the image plane causes loss of focus which can be minimized by having an even number of mirrors located symmetrically about the intermediate lens. The RKS-1 camera, embodying these findings, is described. It is intended for the high-speed photography of flash-light sources and spark discharges.

The Problem of the Concentration of Bromide Ion in the Layers of Multilayer Photographic Materials

A. V. Borin, pp. 64–65

In black-and-white films coated with an emulsion of low sensitivity under the high-speed layer, to protect the latter against halation, interaction can take place between the bromide ion concentration of the two layers. This interaction has been studied experimentally. When the bromide ion concentration in the lower layer exceeded that in the upper, the speed of the latter dropped noticeably, while with ammoniacal emulsions the contrast and fog also dropped. A similar loss in speed is also observed when the emulsion is coated directly onto film base, presumably owing to diffusion of acid from the base. Similar interactions are to be expected in any multilayer film if the bromide ion concentration and pH are not of the same order for all layers.

Kinescope for the Photography of Rapid Processes

V. I. Nekrasov, *Sborn. Leningr. Inst. Inzh. Zh.-D. Transp., No. 155:* 116–126 (1958).

The construction of, and calculations for, a camera for the photography of rapid processes are described. The camera comprises 24 objectives which project images of the object onto different parts of two 9 by 12-cm photographic plates. The shutter is a rotating disk with concentric slits, and is placed between the objectives and the plates. The camera is provided with three types of disk: the normal, which in one revolution opens each objective in turn; a disk for stereoscopic photography, which opens a pair of objectives at a time; and a disk for photography at a higher speed, which opens the 24 objectives in one half a revolution. With the disk rotating at 3000 rpm, the camera can give 1200, 600, or 2400 frames/sec, according to the type of disk. There is also apparatus for synchronizing the camera with other equipment. — *S.C.G.* (Translated from *Referativnyĭ Zhur. Fiz.*, 293, No. 8, 1959.)

Analysis of Developing Agents by Paper Chromatography

Several articles on the identification of photographic developing agents by paper chromatography have been published in recent years. Pannell and LuValle[1] reported R_f values, obtained with a mixture of butanol, acetic acid, and water in the ratio 4:1:5 as solvent and Whatman No. 2 paper, for hydroquinone and its mono- and di-sulfonates, Metol and its sulfonate, *p*-aminophenol, and *p*-phenylenediamine. Sasai, Mizusawa, and Otaka[2] reported R_f values for Metol, hydroquinone, catechol, pyrogallol, *p*-phenylenediamine, diethyl-*p*-phenylenediamine, *p*-hydroxyphenylglycine, and Amidol, obtained with a butanol, acetic acid, water (4:1:5) solvent and an ethyl acetate, acetic acid, water (4:1:2) solvent. Futaki[3] used a butanol, acetic acid, water (4:1:5) solvent and a benzene, acetic acid, water (2:2:1) solvent and reported R_f values for Phenidone, catechol, hydroquinone, diethyl-*p*-phenylenediamine, pyrogallol, Metol, *p*-hydroxyphenylglycine, Amidol, and *p*-phenylenediamine. Mariani and Martinelli[4] used a mixture of 15% water, 80% butanol, and 5% acetic acid as solvent and determined R_f values for catechol, hydroquinone, *o*-aminophenol, *o*-hydroxyethylaminophenol, *p*-aminophenol, Metol, *p*-hydroxyethylaminophenol, *p*-hydroxyphenylglycine, *o*-phenylenediamine, *p*-phenylenediamine, hydroxyethyl-*p*-phenylenediamine, dimethyl-*p*-phenylenediamine, diethyl-*p*-phenylenediamine, Amidol, pyrogallol, 1,2-aminonaphthol, and 1,4-aminonaphthol.

Several recent articles which do not deal specifically with developing agents give data on compounds which are active developing agents or are closely related to well-known developing agents. The R_f values in the tables shown here are based on data given by Barbier and Lederer[5] (Whatman No. 1 paper, descending chromatogram technique); Lissitzky and Roques[6]; Turi[7] (constituents of hair dyes); Ettel, Pospisil, and Deyl[8] (Whatman No. 1 paper); and Keith, Le Tourneau, and Mahlum[9] (Whatman No. 54 paper, descending chromatogram). The solvent and literature reference are given at the head of each column. Numerical R_f values depend on both the solvent and the technique used.

Keith *et al* describe[9] a routine method for the quantitative determination of the di- and tri-hydroxy compounds. The sample to be analyzed is dissolved in 50% ethanol and applied with a micropipet by streaking a 2.5-in. strip on the reference line of the paper. Spots of known compounds are applied on either side of the main band, to be used subsequently to locate the area in the main band in which a compound would be found if it were present in the unknown. After the chromatogram has been irrigated

with the solvent and then dried, the strips which contain the known compounds are cut off and the positions of the compounds are located by treatment with Folin-Ciocalteu reagent diluted 1:1 with water, followed by 20% carbonate solution. Areas are cut from the corresponding portions of the chromatogram of the sample, the phenol derivative is extracted from each area with hot water, Folin-Ciocalteu reagent and sodium carbonate solution are added, and the extract is made up to a standard volume. After the blue color has developed for 2 hours, the optical density is read at 660 mμ and the amount of phenol is determined by comparison with a calibration curve. — *T.H.J.*

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8. V. Ettel, J. Pospisil, and Z. Deyl, *Collection Czechoslov. Chem. Commun.*, *24:* 234 (1959), quoted in *J. Chromatography*, *2:* D22 (1959).
9. R. W. Keith, D. Le Tourneau, and D. Mahlum, *J. Chromatography*, *1:* 534 (1958).

R_f Values as Given in Five Published Papers[5–9]

Compound	Reference: (5) Solvent: Benzene 8, HOAc 2, Water 1	(6) BuOH 78, HOAc 5, Water 17	(7) BuOH 4, HOAc 1, Water 5	(7) BuOH 4, EtOH 1, Water 5	(9) HOAc (20%)	(9) EtOAc 2, HOAc 1, Water 2
2,3-Dimethylhydroquinone	0.0	—	—	—	—	—
Hydroxyhydroquinone	0.01	0.65	—	—	—	—
Hydroquinone	0.07	0.80	0.90	0.91	0.71	0.91
Methylhydroquinone	0.10	—	—	—	—	—
2-Methoxyhydroquinone	0.25	—	—	—	—	—
Ethylhydroquinone	0.30	—	—	—	—	—
2-Ethoxyhydroquinone	0.55	—	—	—	—	—
Propylhydroquinone	0.65	—	—	—	—	—
Resorcinol	—	—	0.90	0.92	0.70	0.91
Catechol	—	0.84	0.90	0.92	0.74	0.92
Pyrogallol	—	—	0.70	0.74	0.63	0.82
Protocatechuic acid	—	—	—	—	0.62	0.86
2,5-Dihydroxybenzoic acid	—	—	—	—	0.66	0.94
Protocatechuic aldehyde	—	—	—	—	0.66	0.91
Gallic acid	—	—	—	—	0.44	0.69
Pholorglucinol	—	—	—	—	0.61	0.74

Compound	Reference: (8) Solvent: EtOH 95, Ammonia 5	(7) BuOH 4, HOAc 1, Water 5	(7) BuOH 4, EtOH 1, Water 5
o-Aminophenol	0.64	0.72	0.82
m-Aminophenol	0.60	0.70	0.74
p-Aminophenol	0.60	0.57	0.74
2,4-Diaminophenol	0.16	0.42	0.38
2,6-Diaminophenol	0.60	—	—
2,4,6-Triaminophenol	0.60	—	—
p-Methylaminophenol	—	0.69	0.58
p-Hydroxyphenylglycine	—	0.50	0.51
2-Aminophenol-4-sulfonic acid	—	0.20	0.17
o-Phenylenediamine	—	0.66	0.74
m-Phenylenediamine	—	0.53	0.58
p-Phenylenediamine	—	0.48	0.54
1,2,5-Toluenediamine	—	0.52	0.55
1,2,4-Toluenediamine	—	0.59	0.70
1,2,3-Triaminobenzene	1.0	—	—
1,2,4-Triaminobenzene	0.79	—	—
2,3,5-Triaminotoluene	0.77	—	—
2,3,6-Triaminotoluene	0.74	—	—
2,4,5-Triaminotoluene	0.74	—	—
p-Phenylenediamine sulfonic acid	—	0.19	0.13

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